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# Contents

FIELD EVALUATION OF HIGHWAY ADVISORY RADIO FOR TRAFFIC MANAGEMENT IN WORK ZONES (Abridgment)
Michael J.S. Faulkner and Stephen H. Richards . . . . . . . . . . 1

USE OF CHEVRON PATTERNS ON TRAFFIC CONTROL DEVICES IN WORK ZONES (Abridgment)
Benjamin H. Cottrell, Jr. . . . . . . . . . . 3

EFFECTIVENESS OF CITY TRAFFIC-CONTROL PROGRAMS FOR CONSTRUCTION AND MAINTENANCE WORK ZONES
John Van Winkle and Jack B. Humphreys . . . . . . . . . . 6

CONCRETE BARRIERS AT TRANSITION ZONES ADJACENT TO TWO-WAY TRAFFIC OPERATION ON NORMALLY DIVIDED HIGHWAYS
Leslie M.G. Pang and Jason C. Yu . . . . . . . . . . 10

ALTERNATIVE SIGN SEQUENCES FOR WORK ZONES ON RURAL HIGHWAYS (Abridgment)
Richard W. Lyles . . . . . . . . . . 13

HIGHWAY-RELATED TORT CLAIMS TO IOWA COUNTIES
R.L. Carstens . . . . . . . . . . 18

PROCEDURE FOR EVALUATING EFFICIENCY OF POWER-OPERATED CUTTING TOOLS IN LOCALIZED PAVEMENT REPAIR
H. Randolph Thomas and David A. Anderson . . . . . . . . . . 24

PORTABLE HYDRODYNAMIC BRINE ROADWAY DEICER SYSTEM (Abridgment)
Mark A. Pickett and John F. Carney III . . . . . . . . . . 30

CRASH TESTING OF A PORTABLE ENERGY-ABSORBING SYSTEM FOR HIGHWAY SERVICE VEHICLES
John F. Carney III . . . . . . . . . . 32

REGULATION OF THE MOVEMENT OF HAZARDOUS CARGOES ON HIGHWAYS (Abridgment)
David M. Baldwin . . . . . . . . . . 37

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*Abridgment*

# Field Evaluation of Highway Advisory Radio for Traffic Management in Work Zones

**MICHAEL J. S. FAULKNER AND STEPHEN H. RICHARDS**

**Studies were conducted at a major maintenance work zone on a rural Interstate highway in Texas to evaluate the use of Highway Advisory Radio (HAR) for traffic management in work zones. The studies consisted of lane distribution, volume and vehicle classification counts conducted before and after installation of the HAR, and a questionnaire survey administered to motorists observed traveling through the work zone. The studies revealed that the HAR had little or no effect on traffic operations in the work zone because of two factors. First, the conventional signing at the work zone was excellent and HAR functioned only as a supplemental source of information. Second, the advanced signing used to encourage motorists to tune to the HAR broadcasts was inadequate in terms of legibility and visibility. Almost 40 percent of the motorists who entered the work zone reported that they did not even see the signing. Even though the HAR system did not significantly affect traffic operations in the work zone, the studies indicate that HAR may have good potential for traffic management in the work zone for certain applications. The HAR hardware performed adequately. Generally speaking, motorists were satisfied with the quality of the broadcasts and supportive of this innovative approach to traffic management in work zones.**

Highway advisory radio (HAR) is a means of providing motorists with pertinent travel-related information over their standard AM car radios. Motorists on a freeway are instructed by signs to tune their car radios to a specially designated frequency (usually 530 or 1610 kHz). At that frequency they hear a live or prerecorded message broadcast from a field transmitter. HAR is intended to supplement visual signing (e.g., conventional highway signs and changeable message signs) where signing alone is inadequate, inappropriate, or inefficient.

HAR has been used in at least eight states with varying degrees of success for applications that range from airport parking control to hazard warning. Most installations have been permanent. In the past, the use of HAR has been restricted somewhat by Federal Communication Commission (FCC) regulations. Its use has also been discouraged by certain operational problems (1).

In 1978, the FCC relaxed some of its restrictions on HAR and thus encouraged the use of HAR at temporary work zones. There have also been advancements in hardware and operational technology in recent years (2). HAR now appears to have great potential as a traffic-management tool at some types of work zones; however, experience with HAR at work zones has been limited.

One of the first work zone applications of HAR in the United States was on a four-lane rural section of Interstate 10, midway between Houston and Beaumont, Texas. A temporary HAR system was used to divert traffic around a resurfacing work site. District 20 of the Texas State Department of Highways and Public Transportation (SDHPT) installed and operated this HAR system.

## DESCRIPTION OF WORK ZONE

The work zone where the HAR was installed was approximately 14 miles long. There were continuous frontage roads through the work area. The resurfacing work required six months to complete.

The work zone had an average daily traffic rate of 20 000 vehicles. Approximately 20 percent of this traffic was truck traffic and a large percentage was commuter traffic.

Figure 1 shows the innovative traffic-control strategy used to handle traffic at the work site. The use of this strategy was prompted by the heavy traffic volumes at the work site, the large percentage of trucks in the traffic stream, and that the existing frontage roads could not structurally withstand heavy truck loads.

All trucks and buses that weighed more than 5 tons were required to use one side of the mainlanes, which were temporarily converted to a two-lane, two-way roadway. Passing was prohibited for the entire length of this two-way section, and the posted speed limit was reduced from 55 to 50 mph.

Passenger cars, pickup trucks, and vans were diverted from the mainlanes and required to use the parallel frontage roads to travel around the work area. The frontage roads, which normally carried two-way traffic, were temporarily converted to one-way operation. The posted speed limit on the frontage roads was reduced from 55 to 50 mph.

To inform motorists of the special traffic conditions and diversion routes at the work zone, an elaborate system of signs was installed at the work site. Channelization devices, including barrels, vertical panels, and paint markings, were also installed at the diversion points on both ends of the work area.

## HAR

From the inception of the innovative traffic-control strategy, it was recognized that the strategy could create a new and unexpected driving experience for motorists. There was considerable uncertainty regarding the safety and operational efficiency of the strategy; therefore, plans were made to use a HAR system to supplement the signs and channelizing devices.

The decision to use HAR was made just before the project began. By the time the HAR equipment had been ordered and installed, and the system licensed, most of the work had been completed. The HAR system was in operation at the work site for less than one month.

### Equipment

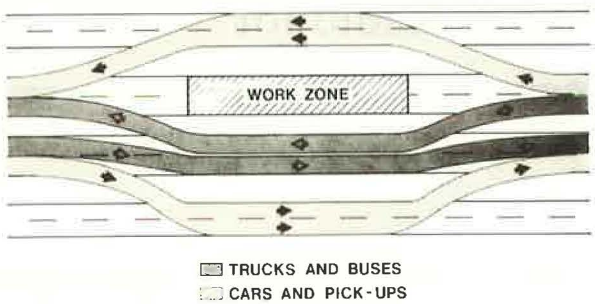
Two 10-watt field transmitters, each with a single, monopole antenna, were installed at the work zone (one on each end of the project). The transmitters broadcast independently but on the same frequency (1610 kHz). The same message was broadcast from each transmitter. The message was recorded on 8-track tapes and played continuously.

The work zone HAR system was operated on a special temporary authority license. The temporary licensing did not require submission of an FCC form 400 or review of the license application by the International Telecommunication Union. The temporary license was granted 63 days after submission of the application.

### Messages

The following message was broadcast continuously to

Figure 1. Traffic control strategy in the work zone.




both east- and west-bound traffic from the two field transmitters:

> Attention Interstate Highway 10 traffic: Due to road construction, all traffic must detour three miles ahead. Cars, pickups, and recreational vehicles move to the right lane and prepare to detour to frontage road. Trucks and buses move to left lane and remain on freeway and on the truck detour route. The truck detour route is carrying two-way traffic so do not pass. The detour is about seven miles in length and all traffic will be returned to the freeway after the detour.

There was a 3-4 s silent pause between each repetition of the messages.

Two versions of the message were evaluated during the study. In one version, the message was read alternately by a man and woman who had no experience in public announcing. They spoke at a speech rate of approximately 130 word/min. In the second version, the message was read by a male professional radio announcer who recited the message at a speed rate of 190 word/min.

Both transmitters broadcast an audible message over a distance of several miles. In fact, HAR broadcasts could at times be heard in Beaumont, which was 20 miles from the work zone. This phenomenon was attributed to the presence of high-voltage power lines near the work zone, which amplified the radio signals. The two independent transmissions could be received simultaneously in the middle of the work zone and a jumbled, inaudible message resulted.

### HAR Signing

Motorists who approached the work zone from either direction were informed of the HAR broadcasts by three advance-warning signs. The black-on-orange signs had 6-in letters and were mounted just off the right shoulder.

The first sign, located 1.5 miles upstream of the transmitter, instructed drivers to tune to 1610 kHz 1 mile ahead for a radio traffic alert. The next sign was located 0.75 mile upstream of the transmitter and it designated the beginning of the radio broadcast zone. The third sign was 1.5 miles farther downstream and it designated the end of the radio zone.

## STUDY OF HAR SYSTEM

Field studies were conducted to evaluate the effectiveness of the HAR system in warning motorists of conditions at the work zone. The studies included lane distribution, volume, vehicle classification counts, and a motorist questionnaire survey. Studies were conducted the week before the HAR system was installed and the week after.

A limited questionnaire survey was developed and administered to 53 motorists in the work zone to evaluate: (a) percentage of motorists who have an operative AM radio, (b) driver familiarity with the work zone, (c) motorist's opinion of the HAR signing, and (d) motorist's opinion of the HAR messages. The questionnaire also was designed to estimate the percentage of motorists who saw the HAR signing and the percentage that attempted to tune to the HAR station.

### Results

Lane distribution, volume, and vehicle classification counts revealed that the innovative traffic-control strategy used at the work zone was very successful. The conventional signs and channelizing devices used at the work zone encouraged up to 94 percent of all cars, pickup trucks, and vans to use the frontage roads and the same high percentage of trucks to use the mainlanes. When the HAR system was installed, these percentages rose slightly to 97 percent.

The effectiveness of the conventional signs and channelization devices made it difficult to evaluate the influence of the HAR on traffic-flow patterns in the work zone. The results of the questionnaire survey, however, provide insight into driver reaction to the HAR signing and messages. The survey results also suggest some apparent deficiencies in the HAR system.

### Survey Findings

Apparently, the HAR signs were too small and lacked target value. Twenty-one of the 53 motorists (40 percent) surveyed said they did not see the HAR advance signing. Many motorists who saw the signs complained that they were too small or hidden by larger, more conspicuous work-zone and freeway guide signs. Advance signing for an HAR system must be adequate if the system is to be effective.

Only 14 of the 32 motorists (44 percent) who saw the signs attempted to tune to the HAR broadcast. The work zone was on a heavily traveled commuter route and more than half of the drivers surveyed had traveled through the work zone several times. Many of these motorists said they failed to tune in because they did not desire additional information about the work zone. This finding suggests that HAR should not be used to broadcast repetitious information to familiar drivers. A few motorists who saw the signs did not tune in because their car radios were broken.

Most of the drivers who attempted to tune to the HAR broadcasts were able to hear the message, and they rated the message quality as fair to good. Generally speaking, most motorists surveyed favored the use of HAR at some work zones.

## DISCUSSION OF RESULTS

HAR has potential as an effective tool for traffic management in work zones. Guidelines need to be developed for the use and operation of HAR in work zones, however. These guidelines should identify conditions that warrant the use of HAR at work zones. These conditions might include the following:

1. Delay--work zones where delay is excessive and more favorable alternate routes exist,
2. Signing effectiveness--work zones where normal construction warning techniques are ineffective or inappropriate, and

3. Accidents--work zones that have higher than normal accident or fatality rates.

These HAR conditions should be established for each specific work zone and should be contained in the traffic control plan. Field studies should also be developed and scheduled routinely throughout the life of the project. These field studies would determine the need for additional information for the motorist and when an HAR system may be applicable in terms of the defined conditions.

In addition to the guidelines, HAR licensing procedures need to be improved. A license for an HAR system currently takes up to six months to obtain. This time should be reduced if HAR and HAR guidelines are to be used effectively and regularly at work zones.

ACKNOWLEDGMENT

We would like to express appreciation to District 20 of the Texas SDHPT for their assistance and cooperation in the study. The research documented herein was part of a highway planning and research study conducted for the Texas SDHPT entitled, Traffic Management During Freeway Reconstruction and in Rural Work Zones. Herman Haenel of the Texas SDHPT is acknowledged for his guidance and assistance in all phases of the research study.

REFERENCES

1. S.H. Richards, C.L. Dudek, and J.M. Mounce. Human Factors Requirements for Real-Time Motorist Information Displays, Vol. 16: Feasibilty of Audio Signing Techniques. Texas Transportation Institute, College Station, Res. Rept. FHWA-RD-78-20, Aug. 1978.
2. W.F. Dorsey. Highway Advisory Radio Potential Site Survey and Broadcast Equipment Guide. Office of Research and Development, Federal Highway Administration, April 1979.

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*Abridgment*

# Use of Chevron Patterns on Traffic Control Devices in Work Zones

**BENJAMIN H. COTTRELL, JR.**

**The objectives of the research were to select the most effective design for the chevron pattern and to evaluate the effectiveness of selected chevron designs under road conditions as compared with currently used designs. In a supplemental test, the effectiveness of the New Jersey concrete barrier was compared with that of the channelizing devices studied. In general, the selected chevron designs were preferred over the currently used patterns. Driver response was found to be not strongly dependent on the channelizing device employed in the taper. A supplemental taper of channelizing devices was found effective for use with the New Jersey concrete barrier.**

The objectives of this research were to select the most effective design of the chevron pattern and to evaluate the effectiveness of selected chevron designs under road conditions. The evaluation compared the effectiveness of traffic control devices bearing the chevron design with that of barricades and channelizing devices that bear the currently used stripings.

The scope of the research was limited to the use of barricades and channelizing devices to provide directional guidance.

## SELECTION OF A CHEVRON DESIGN

The groups of chevron designs shown in Figure 1 were rated subjectively by observers in vehicles at two points--the point of detection (500 ft) and the point of legibility (300 ft). The demonstrations were conducted under both day and night conditions; 32 observers participated. At night, the groups of designs were observed under both high- and low-beam headlights.

The observers rated the pattern groups at the point of detection in terms of (a) the ability to command attention, (b) the ability to warn and alert, and (c) overall appearance. At the point of legibility the pattern groups were rated for (a) the ability to convey a clear, distinct message; (b) the ability to guide and direct; and (c) overall appearance. The sets of parameters were summed for each pattern to obtain two cumulative measures that were compared with those for the other patterns in the group. The mean and standard deviation were calculated and the Wilcoxon ranked sign test was used to statistically rank the patterns with a 0.05 level of significance for a two-sided test. The patterns identified by an asterisk in Figure 1 were selected for field testing.

## FIELD TESTS

The measure of effectiveness deemed most appropriate for the evaluation of channelizing devices under road conditions was the position of the motorists' lane changes. A right-lane closure on a four-lane divided highway was desired because most motorists drive in the right lane and for them a lane change in the work zone would, therefore, be necessitated.

### Procedure

The zonal system shown in Figure 2 was devised to facilitate the collection of data on a driver's lane change as a response to a specific channelizing device. The 350-ft length of the zones is based on the estimated time required to change lanes, which is 4-5 s (1). Zone 1 included the point of detection (500 ft), and zone 2 included the point of legibility (300 ft). Note that the legibility distance does not provide the estimated distance for negotiating a lane change (350 ft).

Traffic counters were placed at the boundaries of the zones with the rubber tubes extending across the right lane of traffic. By determining the difference in the volume count on the traffic recorders that bound a zone, the number of vehicles that

Figure 1. Chevron pattern groups.

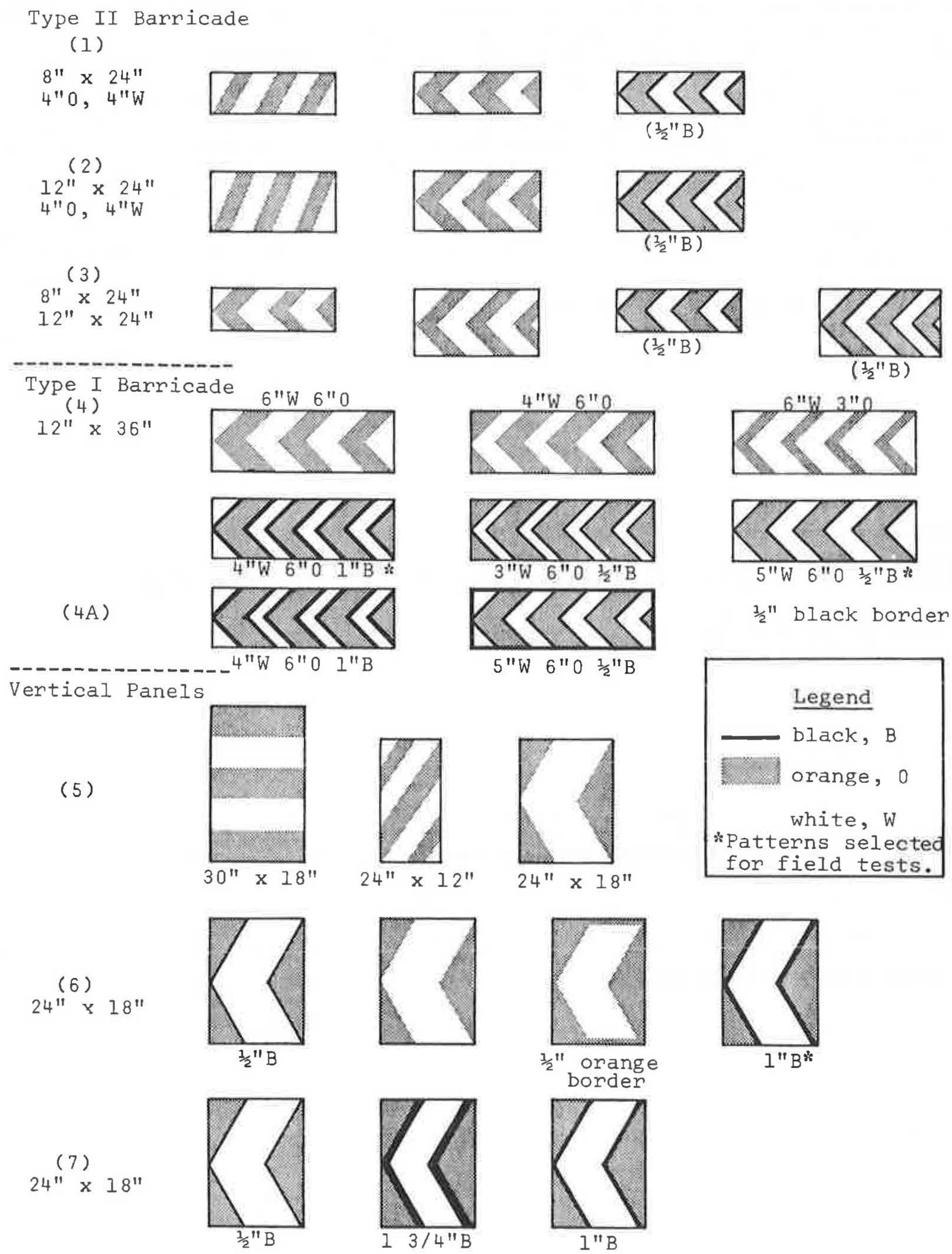



Figure 2. Zone system at test site.

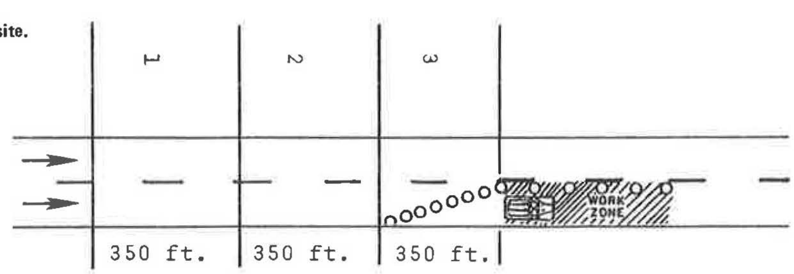
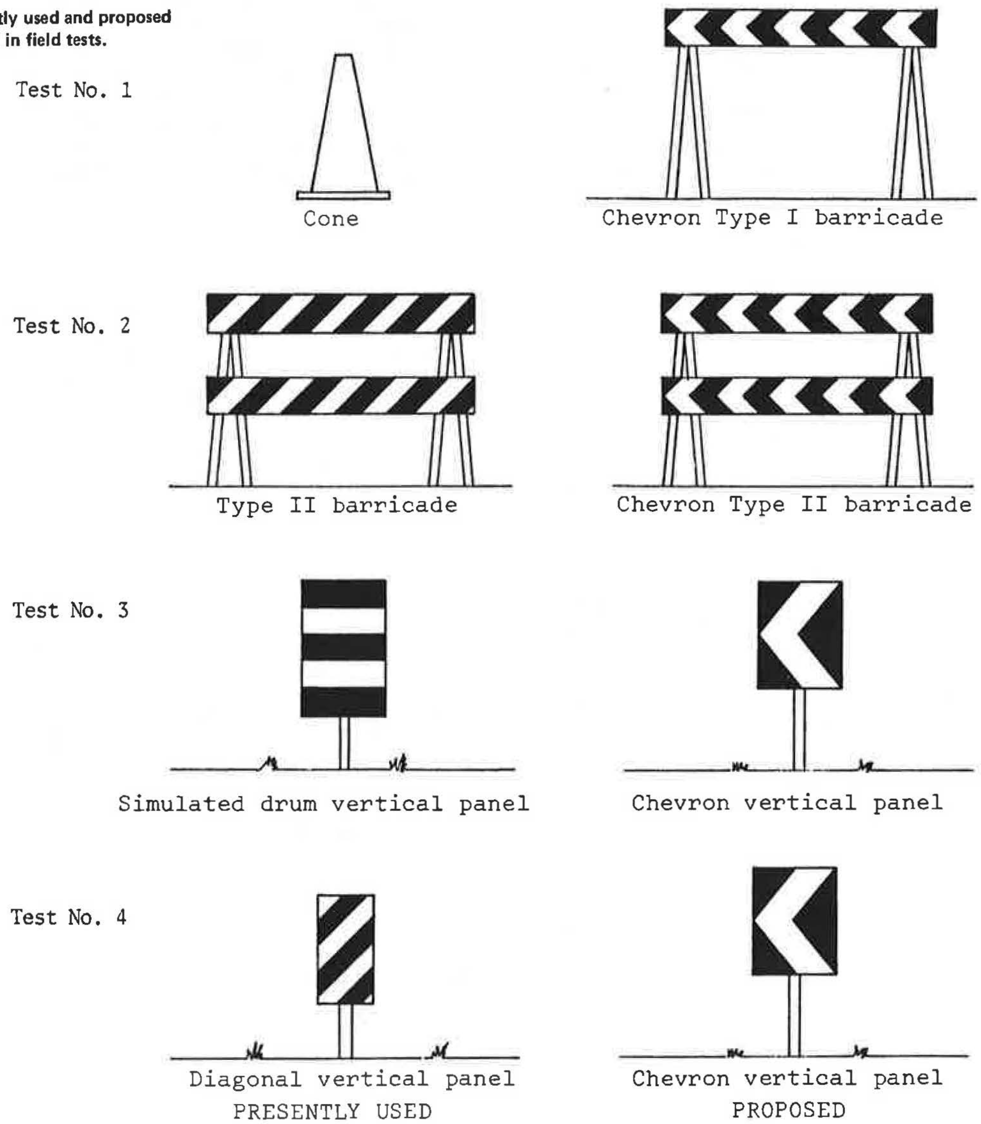


**Figure 3. Currently used and proposed devices compared in field tests.**




change lanes in that zone was obtained. Note that zone 3 was the critical zone because forced mergers occurred there.

The devices compared in the field tests are displayed in Figure 3. Data were collected at two sites, both on an Interstate road, for an average of 21 h for each device except the cone, for which data were collected for 8 h in the daytime only. One of the two sites used a 40-ft taper spacing and the other site used an 80-ft taper spacing. A taper length of 560 ft and a flashing arrow panel were used at both sites.

## Method of Analysis

The distribution of lane changes by zone was determined for each channelizing device, and the percentage of lane changes by zones was obtained based on the total of all lane changes that occur in the zone system. Then, the percentages for the currently used and proposed barricades and channelizing devices in each test were compared.

In an effort to establish a single parameter for the comparison in a test and to relate the zone of lane change to its position relative to the work area, zonal lane changes were weighted. The percentage of lane changes within zone i, where i represents the zone number, and the weighted factors were multiplied and summed. Thus,

$$\text{Weighted lane changes} = 3 \times \text{Zone 1} + 2 \times \text{Zone 2} + 1 \times \text{Zone 3} \quad (1)$$

where zone i is the percentage of lane changes in i. Therefore, the more effective channelizing device is indicated by the higher weighted lane changes. These measures were calculated for day, night, and total (day and night) time periods.

## Results

The channelizing devices favored for each of the four tests are shown in Table 1. The differences in weighted lane changes are included. The results are similar for the two sites except for test 3.

The total weighted lane changes for each channelizing device except the chevron panel and type I barricade were greater at 40-ft spacing than at 80-ft spacing. The total weighted lane changes for the type I chevron barricade and chevron panel did not vary much with respect to the change in spacing.

An additional test was incorporated in the study to compare the New Jersey concrete barrier with the channelizing devices. Based on reports that address

Table 1. Channelizing device designs selected from field test results.

| Test No. | I-81, Cedar Creek, 40-ft spacing | W.L.C.D.[a] | I-81, Narrow Passage, 80-ft spacing | W.L.C.D.[a] |
|---|---|---|---|---|
| 1 | Type I chevron | 8.8 | Type I chevron | 20.0 |
| 2 | Type II chevron<br>Type III diagonal | 0.3 | Type II chevron<br>Type III diagonal | 2.5 |
| 3 | Drum panel | 8.7 | Chevron panel | 11.3 |
| 4 | Diagonal panel<br>Chevron panel | 2.4 | Chevron panel<br>Diagonal panel | 3.3 |

Note: The listing of two channelizing devices indicates equal ratings.
[a]W.L.C.D. = Difference in weighted lane changes between the preferred pattern and less preferred patterns.

work zone safety (2,3), bridge work and pavement reconstruction are associated with a greater increase in accident rates than are other construction activities. The typical work zone setup for these activities in Virginia employs a New Jersey concrete barrier and flashing arrow panel. Since the channelizing devices were being tested while serving as a supplement to the New Jersey barrier, a supplemental taper seemed to be an obvious alternative. The New Jersey barrier was rated equal to the cone for day only and lower than all other devices based on the weighted lane changes. Steady-burn beacons and reflectors about 6 in long were mounted on the New Jersey barrier, which had a slope of 16:1 for the 192-ft taper. The recommendation to use a supplemental taper with the New Jersey barrier will be included in the Virginia supplement of the Manual on Uniform Traffic Control Devices (4).

CONCLUSION

The results of this study do not support a recommendation that the chevron patterns be used on all channelizing devices. Except for those relating to the type I chevron barricade, the conclusions do not clearly and consistently favor the chevron patterns. Since, in general, distinct differences in effectiveness are not attributable to the differences in patterns used on a specific type of device, panel, or barricade, we may conclude that the effectiveness of a channelizing device is not based primarily on the pattern used. The chevron patterns generally were rated slightly better or equal to the currently used patterns with which they were compared. The responses of drivers as measured by the position of lane changing were similar for the two types of patterns.

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REFERENCES

1. H.M. McGee and B.G. Knapp; BioTechnology, Inc. Visibility Requirements of Work Zone Traffic Control Devices. Federal Highway Administration, 1978.
2. H.L. Anderson. Work Zone Safety. TRB, Transportation Research Record 693, 1978, pp. 1-4.
3. R.J. Paulsen, D.W. Harwood, J.C. Graham, and J.C. Glennon. Status of Traffic Safety in Highway Construction Zones. TRB, Transportation Research Record 693, 1978, pp. 6-12.
4. Manual of Uniform Traffic Control Devices for Streets and Highways. Federal Highway Administration, 1978.

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# Effectiveness of City Traffic-Control Programs for Construction and Maintenance Work Zones

JOHN VAN WINKLE AND JACK B. HUMPHREYS

**The purpose of this study was to evaluate the present state of the art of city traffic-control programs for construction and maintenance work zones. Information was gathered through two separate investigations to determine the status of present city traffic-control programs for construction and maintenance work zones and the effectiveness of these programs. A survey was conducted by sending questionnaires to cities in the United States that asked for information related to various aspects of the cities' traffic-control programs in work zones. Responses were rated according to each city's degree of involvement in regulating traffic controls in work zones. The results indicated that the amount of importance cities place on traffic-control progrms for work zones varies widely and the majority of the cities surveyed do a less-than-adequate job in controlling construction and maintenance activity. Work zones in eight of the surveyed cities were studied to evaluate the effectiveness of the cities' traffic-control programs for work zones. This information was used to rate each of the cities' effectiveness and compare it with the survey ratings by using a statistical ranking procedure. A correlation was found between the survey scores and the field investigation scores. This correlation suggests that the quality of traffic control in the work zones is dependent on the degree of involvement the cities have in regulating construction and maintenance work zones.**

With the recent shift of emphasis from the construction of new highways to the rehabilitation and upgrading of existing facilities, a significant effort has been made to improve the quality of traffic control through road construction and maintenance work zones. Much research has been performed to develop more-effective devices for traffic control and standards to use them. As a result of this research, several changes have been made in the Manual on Uniform Traffic Control Devices (MUTCD) (1) and in Federal Highway Administration (FHWA) guidelines for federally funded construction projects.

Since the adoption of this MUTCD, studies are beginning to show that, to a large degree, the standards for traffic-control devices for construction and maintenance work zones and the requirements for their proper use are adequate. A major FHWA research effort conducted by the University of Tennessee, which inspired this study, identified and evaluated more than 100 work zones in 11 states across the United States. It determined that (2) "over two-thirds (of the individual deficiencies identified)...were considered to be adequately addressed in the Manual on Uniform Traffic Control Devices or by the current state of the art."

Another study, conducted by the U.S. General Accounting Office, reviewed efforts by FHWA to increase safety through road construction work zones. This study found that at all levels (3)

1. Officials did not always know how to make work sites safe,
2. They did not always appreciate the need for safety, and
3. They placed higher priority on construction quality, economy, and deadlines.

The review recommended that MUTCD be revised to include specific management guidelines for the implementation of traffic-control measures in work zones.

Many of the major problems researchers are finding lie not with the standards but with management's effort to adequately encourage and enforce better adherence to the standards. To quote a recent Kentucky study (4), "Jobsite safety, as with traffic accident prevention overall, is only as good as its administration follow-through."

Recent research at the University of Tennessee has reviewed the current status of traffic-control programs for cities across the country. This paper analyzes the existing city programs along with field investigations of sites within eight of the surveyed cities.

## STATE OF THE ART

In order to determine the current state of the art of city traffic-control programs for construction and maintenance work zones, a survey was made of city traffic engineers throughout the United States. One hundred randomly selected cities that have populations that range between 50 000 and 1 000 000 were sent questionnaires, and 49 questionnaires were returned. Although the cities were selected on a near random basis, effort was made to obtain questionnaires from cities that were reviewed in the related FHWA study (2) for comparative use in this research.

Twelve questions related to various aspects of the cities' traffic-control management programs for work zones were asked. The questions covered four general areas:

1. Permit and authorization procedures;
2. Development, approval, and implementation of a traffic-control plan and field inspection;
3. Enforcement and training policies; and
4. General problems and areas for improvement identified by the cities.

All questions and a summary of the results of the survey are shown in Figure 1.

The responses to the survey were broken down into two categories--rated and nonrated questions. The five rated questions (1, 4, 5, 8, and 10) were asked to determine how active a role the cities had in regulating the traffic control for construction and maintenance activity within the street right-of-way. The remaining questions were asked to determine what the typical practices were, but the responses did not give an indication of good or bad procedures and were not rated.

**Figure 1. Summary of survey results.**

1. Do you have a permit for street closures incorporating traffic control requests?

| | |
|---|---|
| No | 33% |
| Yes, without traffic control requirements | 22% |
| Yes, with traffic control requirements | 45% |

2. What advance notice do you require for street closures (minor closures--total closure of a local street or partial closure of collector streets, major closures--total closures of collector or total or partial closure of arterial streets)?

| | Number of Cities | | |
|---|---|---|---|
| | Minor or Major Closures | Minor Closures | Major Closures |
| None | 5 | - | - |
| 24 hours | - | 17 | 6 |
| 48 hours | - | 10 | 6 |
| 72 hours | - | - | 8 |
| 1 week | - | - | 7 |
| 2 weeks | - | - | 2 |
| Other | 2 | - | - |

3. Under what circumstances is a permit not required?

| | |
|---|---|
| None/none required | 43% |
| Emergency work | 41% |
| Utility/city forces/contract work | 10% |
| Special cases w/verbal OK | 6% |

4. Is your department actively involved in traffic control plan inspection and/or approval?

| | |
|---|---|
| No | 10% |
| Yes, minor involvement | 63% |
| Yes, major involvement | 27% |

5. Does your department have any employees whose primary duty is to approve traffic control layouts and inspect work zone traffic controls?

| | |
|---|---|
| No | 49% |
| No, employee(s) w/partial duty | 29% |
| Yes | 22% |

6. Who is responsible to develop traffic control plans?

| | |
|---|---|
| Contractor/utilities | 65% |
| Traffic engineering department | 35% |

7. Does your department provide traffic control devices for work done by your department and/or other agencies?

| | |
|---|---|
| City forces only | 45% |
| Department only, or no one | 41% |
| Others | 14% |

8. What are your enforcement policies and penalties for work without a permit and/or non-compliance with an approved plan?

| | |
|---|---|
| None | 24% |
| Shut down job | 45% |
| Shut down job plus fine, arrest and/or revoke permit | 12% |
| Other (combination of fine, revoke permit, arrest) | 20% |

9. Do you have a city manual specifically for traffic control in work zones?

| | |
|---|---|
| No | 53% |
| Yes | 45% |
| No response | 2% |

10. Do you regularly conduct any kind of training program for your employees and/or other agencies?

| | |
|---|---|
| No | 51% |
| Occasionally | 10% |
| Yes, only to city forces | 14% |
| Yes | 24% |

11. What problems are you having with your program, and what improvements would you like to see made?

| | Number of Cities |
|---|---|
| Non-compliance/poor signing procedures | 14 |
| Lax enforcement | 10 |
| Insufficient inspection | 9 |
| Inadequate training | 7 |
| Poor notification/coordination | 7 |
| Weak ordinances to force compliance | 7 |
| Convincing contractors of need for proper traffic control | 3 |

12. How would you rate your city's traffic control program?

| | |
|---|---|
| Insufficient | 29% |
| Adequate | 69% |
| Excellent | 0% |
| No response | 2% |

Table 1. Ratings for questionnaire responses.

| Question[a] | Weighting | Response | Score |
|---|---|---|---|
| 1 | 10 | No | 0 |
| | | Yes, without traffic control requirements | 5 |
| | | Yes, with traffic control requirements | 10 |
| 2 | | Not rated | |
| 3 | | Not rated | |
| 4 | 25 | None | 0 |
| | | Minor involvement | 10 |
| | | Major involvement | 25 |
| 5 | 30 | None | 0 |
| | | Partial | 15 |
| | | Primary | 30 |
| 6 | | Not rated | |
| 7 | | Not rated | |
| 8 | 10 | None | 0 |
| | | Penalty | 10 |
| 9 | | Not rated | |
| 10 | 25 | None | 0 |
| | | Conducted occasionally | 10 |
| | | Conducted regularly for city forces only | 15 |
| | | Yes, open to all agencies | 25 |
| 11 | | Not rated | |
| 12 | | Not rated | |
| Total | 100 | | |

[a]See Figure 1 for questions.

Of the five rated questions, the question that asked whether the cities had personnel whose primary responsibility involved traffic-control planning and inspection for work zones gave the best indication of a city's commitment to regulating traffic control in work zones. Of the 100 points possible, this question was given the highest weighting of 30 points.

Two questions, involving traffic-control plan inspection and approval and training programs, were also considered to be of major importance and were given a weighting of 25 points each. The last two questions, which dealt with permits for street closure and enforcement policies, gave indications of the cities' involvement in these programs to a minor degree and, therefore, were given a lower rating of 10 points each. A listing of the ratings and a breakdown of partial scoring are shown in Table 1.

Although a weighting of the questions was made based on the relative importance of each, the relative rankings of the cities were unaffected by the weighting. That is, cities that scored high on the major (heavier weighted) questions also scored higher on the lower value questions. Cities that received no points or part scores on the major questions scored similarly on the minor questions.

The results of the scoring of the responses are shown graphically in Figure 2, which indicates that the variation in the cities' scores is wide. The average score for all cities was 46.2 points. If we assume that the bare minimum programs require 60 points (part scores on the three major questions and full scores on the two minor questions), 71 percent of the cities had less than adequate programs. In fact, this same percentage scored 50 points or less.

A significant finding of this phase of the study was that, despite the fact that the majority of the city traffic-control programs for work zones were considered to be less than satisfactory, 60 percent of the cities thought that they had an adequate program.

## FIELD INVESTIGATIONS

The next phase of the research was to evaluate the quality of traffic control through urban work zones by using actual field investigations and then to compare the results of these investigations with the survey results. The information used for this analysis was acquired by the University of Tennessee (2).

As part of this FHWA study, 103 construction, maintenance, or utility work zones in 11 states were visited. Data collected from these sites covered many types of conditions, including urban and rural locations, day and night-time activities, stationary and moving operations, and various types of work zones (e.g., roadside, lane closures, and detours) and facilities (two-lane, multilane, and Interstate).

Data were gathered by field investigators through the use of several methods. These methods included use of a data checklist in which various conditions of the site were noted, interviews of workers and local government officials, and documentation of these conditions through extensive use of 35-mm photography.

After an investigator made field investigations, he or she led a panel review by using the 35-mm slides to explain the nature of the work. The panel for each review was composed of a minimum of four professionals experienced in the field of traffic safety. Deficiencies for each site were noted and then rated by the panel according to three parameters--hazard, risk, and preventability. These parameters were defined in the report as follows (2):

> Hazard was understood to be a measure of severity, and risk the probability that an accident would occur. Preventability was understood to reflect the degree to which the hazard and risk associated with the problem would have been reduced had all applicable codes and standard practices been followed and/or current knowledge utilized.

Each of these factors was rated by each panel member on a scale of 0-5. A hazard that rated zero indicated no hazard, and five indicated a very serious safety problem. Similarly, a rating of zero on the risk scale indicated that there was a zero probability that an accident would occur, and a five meant that the probability of an accident occurring was very high. A preventability score of zero indicated that there existed no information as to how the problem could have been corrected and a five suggested that the deficiency could have been eliminated had current standards been followed. These ratings were then recorded on a work zone inspection summary sheet for each site.

Eight cities were common to both the FHWA study and the survey conducted for this research and covered a total of 30 work zones. Four of the cities had only 1 or 2 sites; the remaining four cities had 5-7 sites each. Eighteen of the sites were construction work zones and 12 were utility work zones. Two of the cities had no construction sites and two others had no utility sites. No maintenance work zones were included in this sample.

By using the ratings determined by the previous study, a composite score was calculated for each deficiency of each project by multiplying the average scores for each of the three factors. This product reflected the severity of a given problem area at any given work site. For example, for a score of 1, 1, and 5, the Hazard x Risk x Preventability score was 5. This score reflected that there was very little hazard and risk and that the deficiency could have been corrected by using existing knowledge. As another extreme example, individual scores of 5, 5, and 0 yielded a product score of zero. In this case, although the hazard and risk were very high, because no current information was available on how to treat the given problem, the city was not penalized. These scores were then

**Figure 2. Distribution of survey scores.**

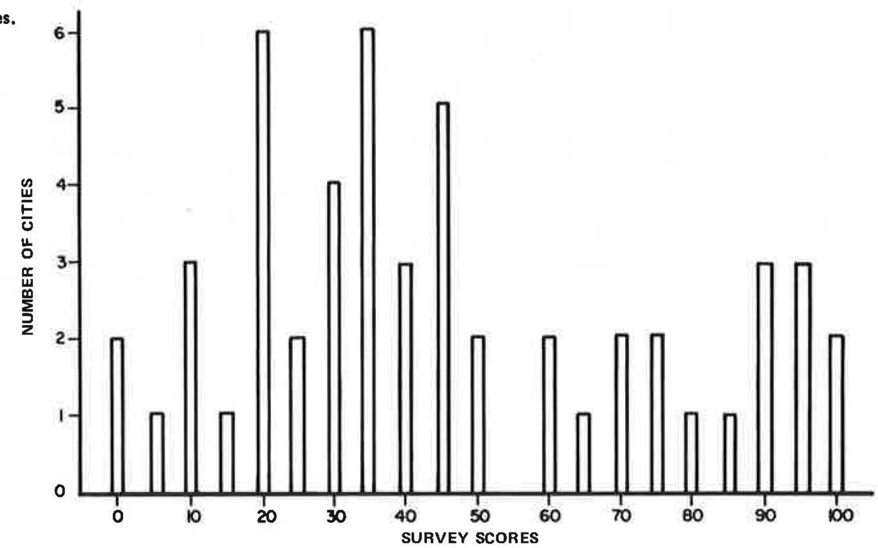


**Table 2. Summary of survey and field investigation scores.**

| City | Questionnaire Survey Score | Hazard x Risk x Probability Score: Construction Work Zone | Utility Work Zone | Average |
|---|---|---|---|---|
| A | 50 | | 15.87 | 15.87 |
| B | 40 | 26.10 | 27.73 | 26.93 |
| C | 100 | 23.04 | 18.45 | 21.89 |
| D | 90 | | 4.67 | 4.67 |
| E | 100 | 17.04 | 9.98 | 15.09 |
| F | 20 | 20.83 | 20.30 | 20.70 |
| G | 45 | 26.90 | | 26.90 |
| H | 20 | 27.42 | | 27.42 |

**Table 3. Rank comparisons among survey and product average ratings.**

| City | Survey Rank | Hazard x Risk x Probability Average Rank | $d^2$ |
|---|---|---|---|
| A | 4 | 3 | 1.0 |
| B | 6 | 7 | 1.00 |
| C | 1.5 | 5 | 12.25 |
| D | 3 | 1 | 4.00 |
| E | 1.5 | 2 | 0.25 |
| F | 7.5 | 4 | 12.75 |
| G | 5 | 6 | 1.00 |
| H | 7.5 | 8 | 0.25 |
| | | | 32.00 |

Notes: $r_S = 1 - [6(32)]/[8(63)] = 0.62$.
Student's $t = 0.62\sqrt{6/[1 - (0.62)^2]} = 1.94$.
n = 8, degrees of freedom = 6.
5 percent confidence interval, critical value = 1.94, 1.94 ≥ 1.94; therefore, cannot reject the hypothesis of correlation at 95 percent level of confidence.

averaged for each city for each type of work zone (construction and utility) and for a combined overall score.

In the FHWA study the preventability score was reversed (5-P) following the rating of the problems so that, in the evaluation of the ratings, areas where further research was needed would be identified. A summary of the survey and product scores for this research is given in Table 2.

Having rated the eight cities based on the field investigations, the next step was to compare these results with the survey results to test for correlation. Because the sample size was small, it was felt that tests for correlation by using absolute value scores for comparison would not be meaningful. Instead, it was decided a rank correlation procedure would be the most-appropriate method.

The cities were first ranked from lowest to highest based on the scores they received from the survey results. In cases where two cities had the same score, their rank position was determined by averaging.

In the same manner, the cities were ranked according to the product scores. These rankings are as shown in Table 3.

To measure the degree of association among the rankings, Spearman's r was calculated by using the following formula:

$$r_s = 1 - [6\Sigma d^2/n(n^2 - 1)] \qquad (1)$$

where $\Sigma d^2$ is the sum of the square of the rank differences and n is the number of cities ranked.

Student's t was then calculated as follows (5):

$$\text{Student's } t = r_s[(n - 2)/(1 - r_s)] \qquad (2)$$

Based on this analysis, correlation of the two rankings could not be rejected at the 95 percent level of confidence.

In summary, the rank correlation between the survey results and the overall field investigation ratings suggests that the quality of the traffic control in work zones is dependent on the degree of involvement the cities have in regulating construction and maintenance work zones. Good traffic management programs for work zones are apparently effective in achieving improvement in traffic control through work zones, and lax programs apparently result in poorer traffic control.

## SUMMARY AND RECOMMENDATIONS

The study surveyed cities across the United States to determine their degree of involvement in regulating traffic controls in work zones. The quality of controls in work zones in these cities was also evaluated. A statistical rank correlation between the quality of city traffic management programs for work zones and the quality of the traffic control in work zones was conducted. This comparison was found to be significant and indicates that better traffic management programs result in better traffic control in the field.

Because the survey showed that, in general, the traffic-control management programs are less than adequate, cities need to institute effective programs to regulate street maintenance and construction activity.

Based on this research, if cities make the effort to implement traffic management programs for work zones, the quality of the traffic control through work zones should improve. The need now is to convince cities of the necessity for providing these programs. It is therefore recommended that a more comprehensive study be conducted of city traffic management programs in work zones to determine the needs and inadequacies of these programs and to recommend and test various proposals to improve the programs.

REFERENCES

1. Manual on Uniform Traffic Control Devices for Streets and Highways. FHWA, 1978.
2. Identification of Traffic Management Problems in Work Zones. FHWA, Final Rept. FHWA-RD-79-4, Dec. 1979.
3. U.S. General Accounting Office. Highway Construction Zone Safety--Not Yet Achieved. U.S. Government Printing Office, Rept. to the Secretary of Transportation, 1978.
4. Jobsite Protection--Good Enough? Rural and Urban Roads, Des Plaines, IL, Vol. 117, No. 9, Sept. 1974.
5. M.J. Moroney. Facts from Figures. Penguin Books Ltd., Harmondsworth, Middlesex, England, 1963, p. 335.

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# Concrete Barriers at Transition Zones Adjacent to Two-Way Traffic Operation on Normally Divided Highways

LESLIE M.G. PANG AND JASON C. YU

**One technique to control traffic around construction zones on four-lane divided highways is to close one of the roadways for construction work and provide two-way, two-lane operations on the opposite roadway. Because of the high frequency of head-on collisions under this type of traffic control, the Federal Highway Administration issued an emergency rule that, among other things, requires that concrete barriers be placed at the transition zones where four-lane operations change to two-lane and vice versa. The objective of this study was to verify whether barriers are justified at transition zones on the basis of accident experience. Data from 14 rural Interstate work sites showed that no head-on accidents occurred at the transitions but several occurred on the two-way, two-lane segments. This indicates that, at least on lesser-traveled highways, the probability of a head-on collision is low because of the minimal volume of oncoming traffic. Therefore, the barrier requirement is questionable on low-volume roadways. By using intuitive reasoning, the effects of project duration and approach speed on accident behavior in transition zones are also discussed.**

Various management strategies have been implemented to control traffic through construction and maintenance work zones on rural, four-lane divided highways. One strategy is to close one roadway for the construction work and provide two-way, two-lane no-passing operations on the opposite roadway. Median crossovers at the transition zones are constructed between the roadways to divert traffic around the closed segment. Refer to Figure 1 for an illustration of the management strategy (1, p. 6B-10).

Under this type of traffic control, an alarming number of severe head-on accidents were found to have occurred (2). As a result, the Federal Highway Administration (FHWA) issued an emergency rule in 1979 that required the use of special traffic control devices along the two-way, two-lane segments and at the transition zones. The rule requires that (3, p. 53 739) "where two-way traffic must be maintained...opposing traffic (must) be separated either with concrete 'safety shape' barriers or with drums, cones, or vertical panels throughout the length of the two-way operation except for transition zones where concrete barriers are to be used in all cases."

This study was concerned with the latter portion of the emergency rule, which requires the use of concrete barriers at all transition zones. The transition zone is defined in this study as the roadway section at which traffic flow is converted from a four- to two-lane operation and vice versa. Because of its traffic flow configuration, transition zones were thought to be susceptible to head-on crashes. The installation of concrete barriers in the transition zone virtually eliminates the possibility of a head-on collision caused by a motorist straying across the centerline.

On the contrary, a number of highway engineers have pointed out the disadvantages with the barriers in response to the FHWA rule (4):

1. The presence of the concrete barriers is a traffic hazard in itself; also, there is an additional hazard during erection and removal of the barriers;
2. Barriers may not be practical in certain situations, such as low traffic volumes, low-speed roadways, or short-term projects;
3. The cost of material and labor for the concrete barrier will increase the project costs;
4. Crash cushions will be required at exposed barrier approach ends and add another fixed-object hazard to the driving environment as well as raise traffic control costs; and

5. A vehicular impact on the concrete barriers will be more severe than would be an impact with other delineation devices, such as drums, cones, and vertical panels.

ANALYSIS APPROACH

FHWA officials thought that concrete barriers are justified at transition zones based on the assumption that these zones are prone to head-on collisions when concrete barriers are not used. This study critically examined this assumption by reviewing the accident experience at transition zones without concrete barriers and determining the frequency of actual and potential head-on crashes at these zones. Potential head-on accidents are reported incidents where a vehicle or vehicles cross the centerline and enter the opposing traffic lane without colliding with the oncoming vehicles. It is hypothesized that if the incidence of head-ons are relatively low or nonexistent at the transition zones that do not have concrete barriers, the existing delineation devices (drums, cones, and vertical panels) are adequate, and concrete barriers are, therefore, unnecessary.

Construction work zone accident data were provided by the accident records divisions of the Nebraska Department of Roads and the Iowa Department of Transportation. Accident experience at a total of 14 work zones located at 16 projects that used two-way two-lane traffic control on normally divided highways was examined. All of the projects were located on various rural segments of Interstate 80 throughout Nebraska and Iowa. Table 1 presents descriptions of the projects and the project work zones examined in this study. The project period included the years 1977-1979.

**Figure 1. Two-way, two-lane traffic operation on highways that are normally divided.**

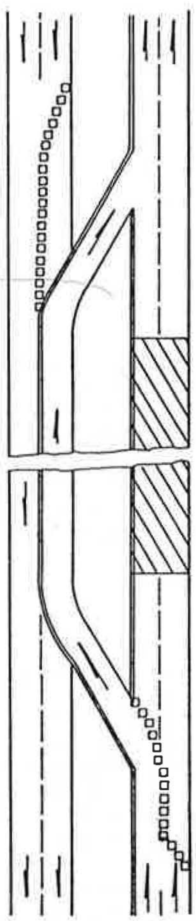



**Table 1. Project background.**

| Project No. | Type of Construction | Work Site Length (miles) | Duration (days) | Average Daily Traffic |
|---|---|---|---|---|
| 1 | Bridge repair | 0.7 | 127 | 8 500 |
| 2 | Pavement repair | 7.3 | 115 | 10 600 |
| 3 | Pavement repair | 5.3 | 116 | 9 400 |
| 4 | Bridge repair | 0.8 | 123 | 10 300 |
| 5 | Bridge repair | 0.6 | 112 | 10 400 |
| 6[a], 7[a], 8[a] | Bridge repair | 1.3 | 79 | 13 000 |
| 9 | Bridge repair | 1.6 | 87 | 12 500 |
| 10 | Pavement repair | 3.9 | 124 | 11 600 |
| 11 | Pavement repair | 4.8 | 118 | 8 500 |
| 12 | Pavement repair | 3.7 | 109 | 9 400 |
| 13 | Pavement repair | 4.6 | 48 | 11 000 |
| 14 | Bridge repair | 1.9 | 120 | 15 300 |
| 15 | Pavement repair | 7.0 | 116 | 12 600 |
| 16 | Pavement repair | 6.0 | 69 | 11 400 |

Note: All projects were located on I-80 in rural areas of Nebraska and Iowa.
[a]Because of the close proximity of these projects, all were contained in a single work zone.

DISCUSSION OF FINDINGS

Table 2 gives the summary of accident statistics at all project locations. The accident data are based on an estimated total of 16 048 700 times a vehicle entered one of the 32 transition zones reviewed. The results also represent a cumulative total of 1463 project days. As given in Table 2, a total of 44 accidents were reported at the rural I-80 work sites studied. Thirty-four out of the 44 total accidents occurred within the transition zone, but none of them were head-on collisions. Four head-on accidents occurred on the two-way, two-lane segments away from the transitions.

The absence of head-on collisions at the reviewed transition zones raises questions on the necessity for concrete barriers at those locations. However, examination of the nature of the accidents in the transition zones showed that more than half of them (56 percent) had the potential of becoming head-on collisions. The collision diagram of accidents in a transition zone is illustrated in Figure 2. The reason why the potential incidents did not result in an actual head-on accident was because no immediate traffic was in the opposing lane when the errant vehicle crossed the centerline. Therefore, at least on relatively low-volume highways, delineation devices appear to be adequate at transition zones, assuming that they are placed properly.

The direct relationship between head-on accident rate and traffic volume is supported by a regression analysis by Pang (5). In his study, he found a high correlation between the accident rate in a transition zone and the annual average daily traffic (AADT) for a range between 8500 and 13 000 vehicles/day. At a correlation coefficient of 0.75, the linear relationship between the two variables was determined to be

$$Y = -789.75 + 89.45 X_1 \quad (1)$$

where Y is the transition zone accident rate per 100 million entering vehicles and $X_1$ is AADT in 1000 vehicles/day.

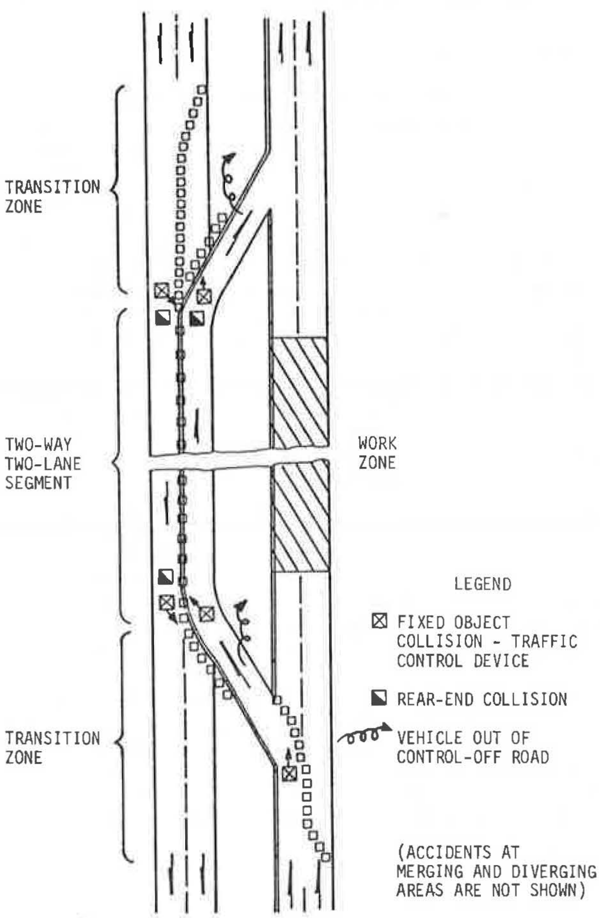
This indicates that, as AADT increases, the accident rate at transition zones also increases. If

Table 2. Accident summary.

| Project No. | Entire Project Length: Total No. of Accidents | No. of Head-On Accidents | Total Accident Rate[a] | Transition Zones Only: Total No. of Accidents | No. of Head-On Accidents | Transition Zone Accident Rate[b] |
|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 3 | 0 | 67.31 | 3 | 0 | 247.04 |
| 3 | 4 | 1 | 68.99 | 2 | 0 | 183.52 |
| 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 1 | 0 | 141.42 | 1 | 0 | 86.27 |
| 6[c], 7[c], 8[c] | 2 | 0 | 150.96 | 2 | 0 | 194.74 |
| 9 | 7 | 2 | 397.81 | 5 | 0 | 460.32 |
| 10 | 6 | 0 | 102.81 | 6 | 0 | 400.96 |
| 11 | 7 | 0 | 140.44 | 5 | 0 | 481.51 |
| 12 | 1 | 0 | 26.36 | 0 | 0 | 0 |
| 13 | 2 | 0 | 82.35 | 2 | 0 | 378.79 |
| 14 | 5 | 0 | 143.80 | 3 | 0 | 163.93 |
| 15 | 3 | 0 | 29.32 | 3 | 0 | 205.25 |
| 16 | 3 | 1 | 63.56 | 2 | 0 | 254.26 |
| Total | 44 | 4 | 101.08[d] | 34 | 0 | 218.33[d] |

[a]Accidents per 100 million vehicle miles.
[b]Accidents per 100 million entering vehicles.
[c]Because of the close proximity of these projects, all were contained in a single work zone.
[d]Mean.

Figure 2. Collision diagram of accidents in transition zone.




we assume that a certain percentage of the accidents in a transition zone involve head-on collisions, a high correlation would be expected to also exist between traffic volume and head-on accident rate. That is, as AADT increases, the head-on accident rate at the transition zone also increases.

Besides traffic volumes, two other variables also appear to affect the head-on accident behavior at transitions--project duration and approach speeds.

Project duration is the time interval during which traffic flows through the transition zones of the project work site. A strong correlation was found between the accident rate in a transition zone and project duration (6, p. 83). With a correlation coefficient of 0.80, the linear relation between the two variables is as follows:

$$Y = 818.26 - 6.42 X_2 \quad (2)$$

where Y is the accident rate in the transition zone per 100 million entering vehicles and $X_2$ is the project duration in days.

The above equation indicates that, as project duration increases, the accident rate at the transitions decreases. Therefore, for projects of short duration, a higher accident rate is expected in the transition zone. Graham arrived at the same conclusion regarding accident rates in construction zones in general (6, p. 83).

Again, assuming that a certain percentage of accidents in transition zones involve head-on collisions, it is anticipated that for projects of short duration, the head-on accident rate is higher than that for longer-term projects. An interpretation why projects of short duration have higher accident rates is that most accidents occur in the early days of the project. At that time, motorists do not expect the construction work or its special traffic controls and, as a result, are prone to accidents. As the project progresses, this unexpectancy, particularly of local motorists, decreases and the accident frequency is expected to decline. In determining the overall accident rate, long-term projects would have to average the high- and low-accident periods, whereas short-term projects just have the early high-accident period.

Since the accident rate in the transition zone increases with the shorter project duration, one plausible conclusion is that concrete barriers may be needed for short-term projects. But these installations may not be cost effective when considering the actual reduction in the number of accidents during such a short period. On the other hand, long-term projects are expected to have a greater number of accidents due to a longer period of exposure. Thus, installation of concrete barriers would be more economically justified for long-term projects than for short-term ones, assuming that they are needed at all. Remember that the accident experience from the sites in this study failed to support the necessity of barrier installation for low-volume roadways.

In regard to approach speeds, it can be expected that, as speed to the transition increases, the chances of a head-on collision would also increase. This is because at higher speeds vehicles would have a greater tendency to stray out of their lanes, particularly at curves such as those present at transition zones. This is implied in recent roadway delineation research (7). By using this reasoning, concrete barriers appear to be justified at transition zones where approach speeds are high. It is difficult to see a need for barriers at zones that have low approach speeds since the head-on accident frequency is expected to be low under those circumstances.

CONCLUSIONS

This paper was prepared with the aim of collecting, tabulating, and analyzing accident data from construction and maintenance zones to determine the validity of the requirements for concrete barriers at transition zones as part of a FHWA emergency rule.

The results of this study and the findings based on past research indicate that concrete barriers do not appear to be justified at those transition zones located on relatively low-volume roadways. The accident data showed that the occurrence of head-on collisions at transition zones was nonexistent at the rural sites reviewed. When errant vehicles did stray into the opposing traffic lanes within these zones, oncoming vehicle volumes were low so that no collisions occurred.

Intuitively, it appears that concrete barriers may be needed at the transitions during the early days of the project, due to the relatively low driver expectancy of the new traffic patterns. However, attention must be given to costs, particularly on short-term projects. Barriers also appear justified at transition zones where approach speeds are high because of the increased probability of a vehicle straying out of its lane due to the geometrics of the transition.

REFERENCES

1. Manual on Uniform Traffic Control Devices for Streets and Highways. FHWA, 1978.
2. Safety in Construction and Maintenance Zones--Two-Way Traffic on Normally Divided Highways. FHWA, Bull., Dec. 20, 1978.
3. Traffic Safety in Highway and Street Work Zones; Separation of Opposing Traffic. Federal Register, Rules and Regulations, Vol. 44, No. 181, Sept. 17, 1979.
4. Summary of Comments and Suggestions of FHWA Docket No. 79-31. Office of Highway Operations, FHWA, 1980.
5. L.M. Pang. Evaluation of Centerline Treatment Used for Two-Way, Two-Lane, No-Passing Operations on Normally Divided Rural Freeways. Department of Civil Engineering, Univ. of Nebraska, Lincoln, M.S. thesis, Dec. 1979.
6. J.L. Graham. Accident and Speed Studies in Construction Zones. FHWA, FHWA-RD-77-80, June 1977.
7. W.A. Stimpson. Field Evaluation of Selected Delineation Treatments on Two-Lane Rural Highways. FHWA, FHWA-RD-77-118, Oct. 1977.

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*Abridgment*

# Alternative Sign Sequences for Work Zones on Rural Highways

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**Two experiments were done on a two-lane rural road (US-2) in central Maine to evaluate the effectiveness of alternate signing sequences for providing warning to motorists of construction and maintenance activities that require a lane closure on the road ahead. The signs tested included a standard Manual on Uniform Traffic Control Device (MUTCD) warning sequence, the same sequence on both sides of the road augmented with continuously flashing beacons, and a sequence of symbol signs. Data were collected covertly on random motorists by using a combination of inductance loops imbedded in the roadway and piezoelectric cable sensors on the road surface. Analysis of the data showed that (a) the most effective sign sequence was the MUTCD sequence augmented with flashing beacons, (b) the symbol sign sequence appeared to be at least as effective as the standard sequence, and (c) in no instance did the sign sequence appear to cause confusion or potentially dangerous abrupt motorist reaction.**

Over the past several years interest has increased in the safety aspects of construction and maintenance activities undertaken when traffic is maintained. Specifically, How can the safety of both passing motorists and the workers be assured while traffic is maintained? Relative to the traffic, the key issues are to alert the approaching motorists to the activity to be encountered ahead and to reduce their speeds in advance so that they can stop safely if the need arises nearer, or in, the work area.

Previous research in this area has ranged from information needs (1), through evaluations of barriers and barricades (2,3), to questions of liability (4,5). Several state-of-the-art reviews are also available (e.g., King and others 6). The Federal Highway Administration's (FHWA) recent programs have been reviewed by Warren and Robertson (7). Within this context, two experiments were undertaken in 1977 to examine several alternative sign sequences for work areas in rural, two-lane situations.

EXPERIMENT IMPLEMENTATION

The original designs for the experiments, (6) were modified prior to implementation in Maine. Two sites were used on US-2 between Skowhegan and Newport, Maine:

1. The long zone was the reconstruction of a two-lane bridge deck where traffic was maintained on one lane at virtually all times during construction, and
2. The short zone was staged to resemble a maintenance operation (e.g., a culvert replacement) with one lane of traffic maintained during the daylight hours and removed at night.

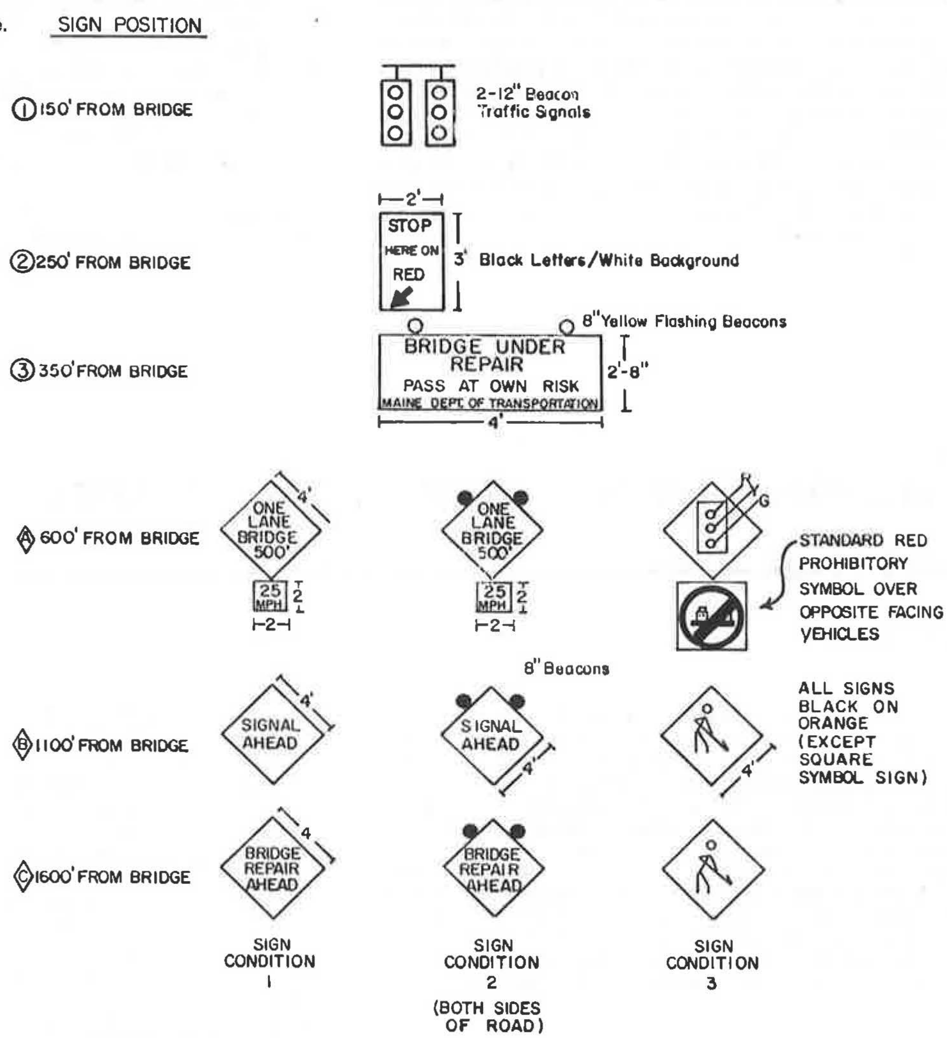
The basic experiment situation was to erect a specified sign sequence in advance of one of the work areas (both approaches to the sites were used) and collect data as motorists approached and passed the signs and eventually passed through the work area. Data were automatically collected (unbeknown to the motorists) from inductance loops embedded in the pavement and piezoelectric cable sensors taped to the road surface.

The sign sequences examined in each experiment are shown in Figures 1 and 2. Although the specific messages differ somewhat, the types of signs tested in each instance were similar. The short-zone experiment was run only during the day, and the long-zone experiment was run during both the day and the night.

The raw data obtained from the automatic collection system (8) were primarily converted to a series of speeds (typically a mean speed over a 200-ft link) for each vehicle and constituted the set of dependent variables in the ensuing analysis (e.g., Where did speed reductions occur?). Data were also available on vehicle type (i.e., two or two or more axles), direction of travel, day of week, time of day, weather conditions (i.e., dry or wet), whether vehicles were in queue or not (i.e., 6-s headway or not), presence of opposing traffic close to the work area (short zone only), and signal color (long zone only). Insofar as possible, the data analysis accounted for potential confounding effects due to the independent variables other than sign sequence displayed (e.g., the analysis was controlled for signal color for the long-zone experiment).

Traffic control at the short zone (short lane closure) was passive insofar as a truck and barricades were present but not workers or a flagger, whereas control at the long zone (long lane closure)

Figure 1. Sign sequences in long zone.




NOTES: SQUARE SYMBOL SIGN: WHITE BACKGROUND WITH RED CIRCLE AND DIAGONAL.

8' BEACONS ON SIGNS ARE AMBER AND CONTINUOUSLY FLASHING

SIGNS 1, 2, AND 3 ALWAYS PRESENT (MAINE DOT REQUIREMENT) ALTHOUGH THEY DO NOT CONFORM WITH THE "MANUAL ON UNIFORM TRAFFIC CONTROL DEVICES" NOR WITH THE "UNIFORM VEHICLE CODE" was accomplished with a standard traffic signal. Figure 3 shows the sensor array for data collection on the westbound approach to the short zone. The array for the long zone was similar although data collection for the westbound approach began before the first sign was in view (due to terrain).

SUMMARY OF RESULTS

The analysis of the data primarily consisted of a series of statistical comparisons of the mean vehicle speeds at various points on the approaches to activities in the work zone. Key elements in the analysis were the separating of differential sign effects from those of other confounding factors (e.g., signal color in the long zone).

Summary of Long Zone

As an example of some of the results, Figure 4 shows

Figure 2. Sign sequences in short zone.

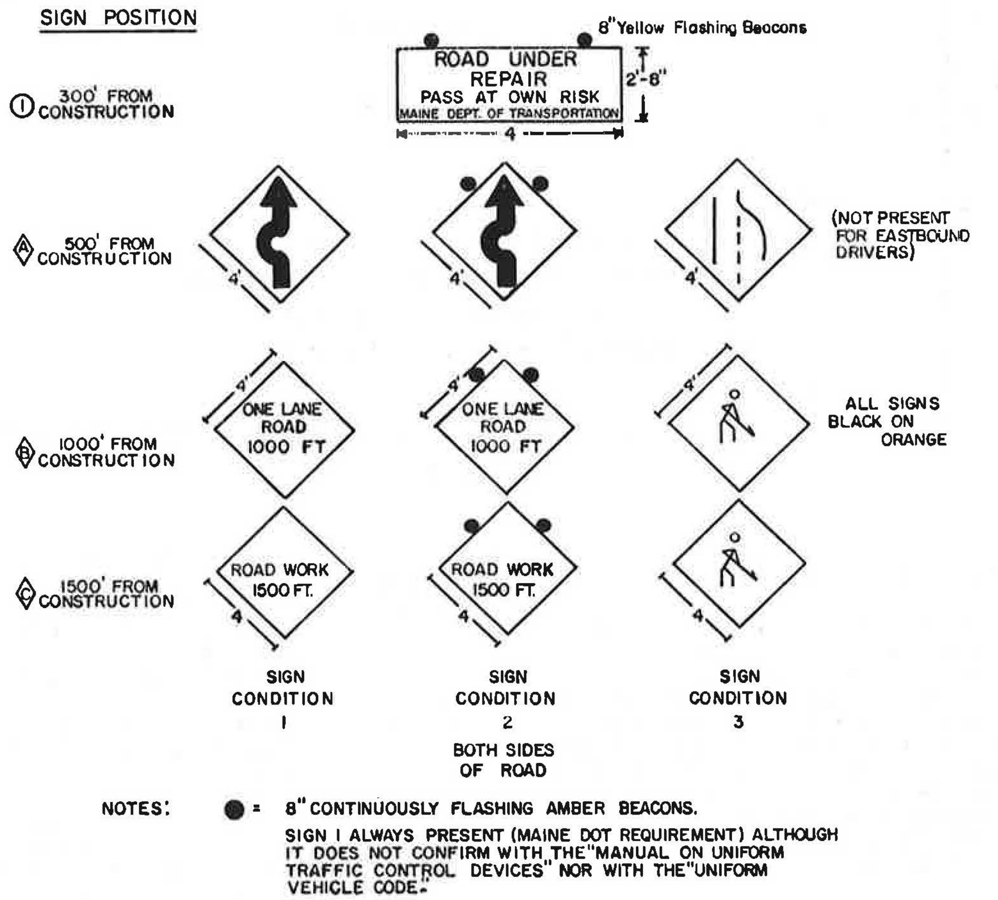



Figure 3. Typical sensor array.

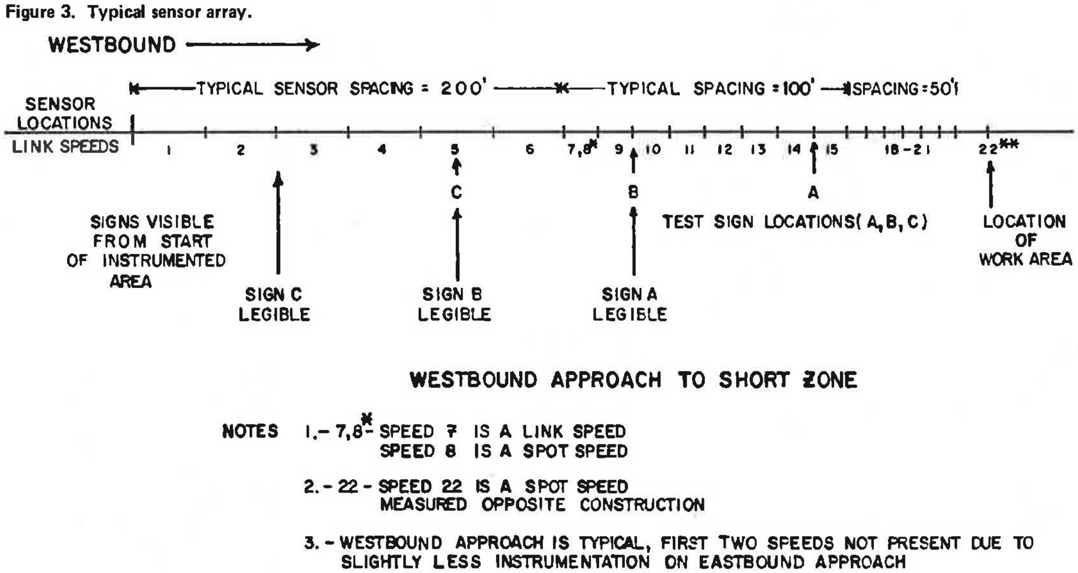
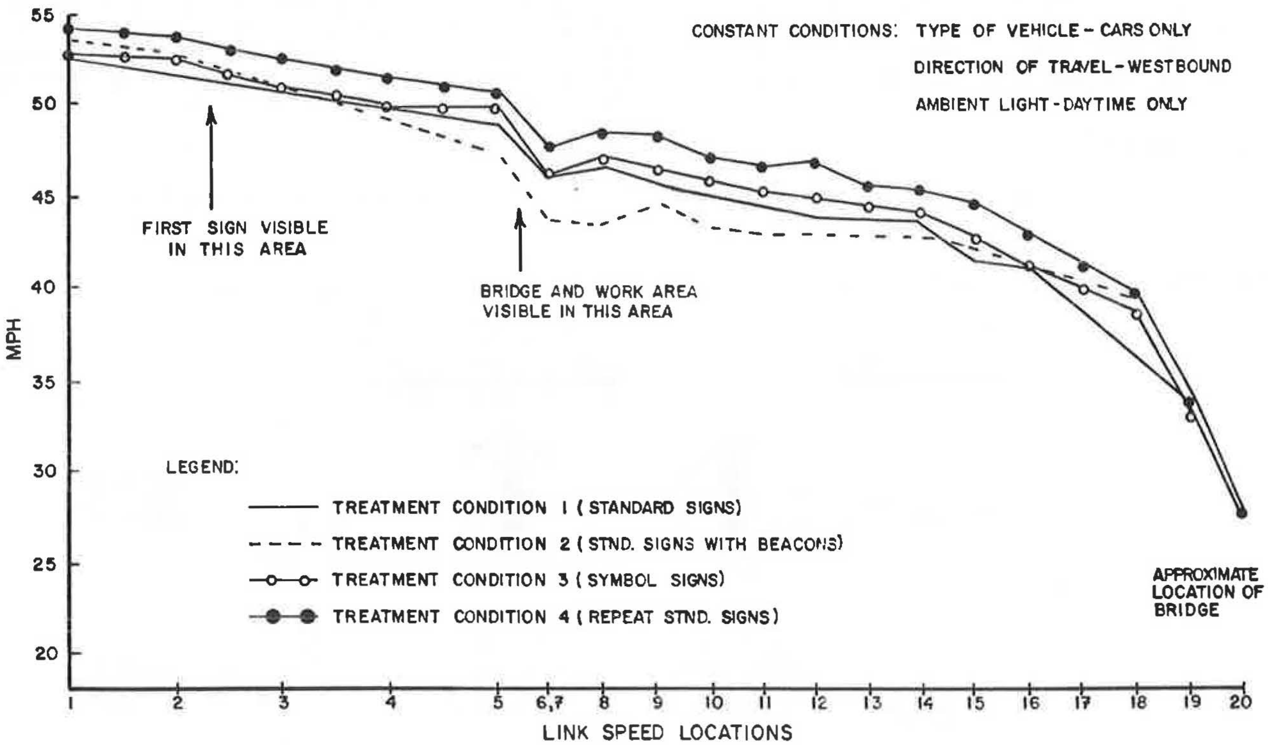


**Figure 4. Mean speed profile in long zone.**




the mean speed profile for the westbound approach for the motorists who were exposed to different sign sequences (note that the first sequence, standard signing, was repeated as a base). These results illustrate the basic superiority of the lighted signs (insofar as lower speeds are concerned) over part of the approach. Similar data (not shown) indicated that the lighted signs were even more effective at night and over a longer distance. By way of a brief summary, the experiment in the long zone dealt with an explicit situation where approaching motorists saw both warning signs and a traffic signal on a rural, two-lane road. Within that context, the following conclusions are offered:

1. Where first the signs, then the signal, and then the work area became visible, the effects of the sign were significant and gave way eventually to the signal effects.
2. Once the signal color was established, all motorists slowed to similar speeds within 600 ft of the work area.
3. Relative to the differential effects of the various sign sequences, (a) the difference between the effects of standard and symbol signs (treatments 1 and 3, respectively) was not significant; (b) differences between lighted and unlighted signs were significant; the former was more effective earlier on the approach; and (c) the maximum difference in effectiveness (in b) was about 3 mph during the day and 4 mph at night at a distance of 1400 ft at night and 1000 ft during the day.
4. Vehicles stopped at the signal stop line or the work area appeared to have no effect on approaching motorists until they were quite close.

Note that the analysis of the long zone excluded consideration of vehicles that had more than two axles because data were insufficient for the analysis to be conclusive.

## Summary of Short Zone

The experiment in the short zone, although a somewhat different situation, yielded results similar to those just summarized--that is, the basic superiority of lighted signs over unlighted ones relative to slowing approaching vehicles. By way of a brief summary of the experiment situation, the short zone consisted of a common situation where routine maintenance activities require the temporary closure of one lane of a two-lane road and where traffic control at the site is basically passive (e.g., granting of the right-of-way is left to the motorists). In this experiment the three test sign sequences were compared to each other and to a base condition where no activities or signs were present. A summary of the conclusions for the short-zone experiment is as follows:

1. Detailed analysis showed that the effectiveness of one set of signs over another was not correlated with the type of vehicle, nor was it correlated with whether or not vehicles were approaching from the opposite direction (with one exception).
2. Relative to the base condition (no signs or activity), the analysis showed that all motorists slowed as they approached the work area. Overall decreases ranged from 12.4 to 20.9 mph over approximately 2400 ft on the westbound approach (where a lane change was necessary at the actual closure) and from 3.1 to 7.0 mph on the eastbound approach (no lane change was necessary).
3. In virtually all instances, the sequence that caused the most substantial speed reduction was the lighted signs. For example, the lighted standard signs were from 47.4 to 118.8 percent more effective than the unlighted signs. Actual magnitudes of the speed reductions ranged from 20.9 mph (slowing from an initial speed of 52.1 mph to 31.2 mph at the closure) for the lighted signs to 12.4 mph (slowing from 53.1 mph to 40.7 mph) for the unlighted stan-

dard signs. (Both examples were for motorists who were opposed in the vicinity of the lane closure traveling in the westbound direction.)

4. Although results were somewhat conflicting for the symbol signs, the effectiveness was never any less than that for the standard word message signs.

## SUMMARY AND CONCLUSIONS

Two experiments were conducted to evaluate the effectiveness of three different types of signs for warning motorists on rural roads of a work area on the road ahead that requires a lane closure. Whereas one experiment was concerned with a closure that required supplementary traffic control (i.e., a traffic signal), the other depended on the signs and a passive control only. In both instances relatively similar results were found:

1. The most-effective sign sequence in virtually all instances was one that was flasher augmented; in one instance in the second experiment, the effectiveness was twice that of similar signs that had no lights for slowing vehicles in the vicinity of the lane closure.
2. Symbol signs were generally at least as effective as the standard sequence in slowing approaching motorists.
3. When another traffic control device was present (i.e., a traffic signal), the effects of that device dominated those of the signs as the motorists got closer.
4. In no instance did any of the signs appear to cause any abrupt motorist reactions that might be hazardous in and of themselves.

Based on these results, if maximum effectiveness is desired, signs augmented with flashing beacons should be considered as an effective device for advance warning. They should be given special consideration if approach speeds are likely to be high, advance visibility is poor, or the open lane is narrow or otherwise requires much lower than normal speeds adjacent to the construction site.

## ACKNOWLEDGMENT

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## REFERENCES


1. R.F. Pain and B.G. Knapp. Motorist Information Needs in Work Zones. ITE Journal, Arlington, VA, April 1979.
2. M.E. Bronstad and C.E. Kimball. Crash Test Evaluation of Temporary Traffic Barriers. TRB, Transportation Research Record 693, 1978, pp. 13-18.
3. F.N. Lisles. Evaluation of Timber Barricades and Precast Concrete Traffic Barriers for Use in Highway Construction Areas. TRB, Transportation Research Record 693, 1978, pp. 18-25.
4. L.W. Thomas. Liability for Improper Traffic Signaling, Signing, and Pavement Marking. TRB, Transportation Research Record 693, 1978, pp. 4-6.
5. D.C. Oliver. Tort Liability: Special Problems Encountered by Highway Agencies and Contractors in Designing Work Zone Layouts. TRB, Transportation Research Record 693, 1978, pp. 47-51.
6. G.F. King, P. Abramson, J.W. Cohen, and M.R. Wilkinson; KLD Associates, Inc. Experimental Design to Evaluate MUTCD and Other Traffic Controls for Highway Construction and Maintenance Operations on Two-Lane Highways. Transportation Systems Center, U.S. Department of Transportation, Huntington Station, NY, 1977.
7. D.L. Warren and D. Robertson. Research in Work Zone Traffic Control: Status Report. ITE Journal, Arlington, VA, April 1979.
8. M.L. Lanman III. The Maine Facility: Capability for Rural Road Research. ITE Journal, Arlington, VA, Dec. 1978.
9. R. Lyles. Alternative Sign Sequences for Work Zones on Rural Highways. FHWA, Final Rept., FHWA/RD-80/162, 1980.
10. R. Lyles. Alternative Sign Sequences for Work Zones on Rural Highways. FHWA, Executive Summary, FHWA/RD-80/163, 1980.


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# Highway-Related Tort Claims to Iowa Counties

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**Tort claims that result from alleged highway defects have introduced an additional element in the planning, design, construction, and maintenance of highways. A survey of county governments in Iowa was undertaken in order to quantify the magnitude and determine the nature of this problem. This survey included the use of mailed questionnaires and personal interviews with county engineers. Highway-related claims filed against counties in Iowa amounted to about $52 million during the period 1973 through 1978. More than $30 million in claims were pending at the end of 1978. Settlements of judgments were made at a cost of 12.2 percent of the amount claimed for those claims that had been disposed of, not including costs for handling claims, attorney fees, or court costs. Problems that resulted in claims for damages from counties have generally related to alleged omissions in the use of traffic control devices or defects (often temporary) that result from alleged inadequacies in highway maintenance. The absence of stop signs or warning signs often has been the central issue in highway-related tort claims. Most frequently alleged maintenance problems have included inadequate shoulders, surface roughness, ice or snow conditions, and loose gravel. Eight recommendations resulted from this research. These are directed toward reducing the potential exposure of counties to tort liability.**

The 99 counties in Iowa are responsible for a system of approximately 90 000 miles of collector and local service highways. Nearly 3.5 billion vehicle miles of travel occur on this system annually. This travel results in about 200 fatalities from traffic accidents.

Each accident on a county highway, and especially each serious accident, introduces the potential for a damage claim against a county. Since any highway segment is imperfect in some respect, the basis for a claim can grow out of any traffic accident.

## BACKGROUND

The goal of this research was to improve highway safety and reduce the potential liability of counties from accidents related to alleged imperfections in highway facilities or in connection with essential highway-related activities. This goal was addressed by focusing on those safety problems that have resulted in highway-related tort claims against counties.

The Code of Iowa was amended in 1967 to permit claims and suits against cities and counties for tort damages. Liability is imposed whether it arose out of a governmental or proprietary function. Hence, virtually no highway-related activities are carried out by counties in Iowa that are barred from tort claims.

Various chapters of the code charge the county supervisors and engineers to keep secondary roads in the best condition practicable, provide details on the performance of certain maintenance tasks, mandate that local traffic control devices conform to the state manual, direct local authorities to place such traffic control devices as they may deem necessary, and have specific provisions to deal with stop and yield signs--stop signs at particularly dangerous highway grade crossings of railways and additional warning signs at unusually dangerous places. Collectively, these sections of the code afford ample basis for highway-related tort claims against counties in Iowa.

Typical low-volume roads found on county systems are constructed to lesser standards than high-volume facilities. Although the logic of this approach is inescapable, none of the seemingly valid reasons for adhering to lesser standards on a low-volume highway affords a suitable defense in litigation. A seriously injured plantiff, or relatives who represent the estate of a person killed in a highway accident, will exploit any discrepancy between an ideal standard and the imperfect highway segment where an accident occurred.

This research was undertaken to quantify the problem of highway-related tort claims against counties and to seek solutions that would make travel on county highways safer and reduce the frequency and magnitude of claims. The solutions sought were assumed to be constrained by realistic fiscal limitations and were intended to render an existing system, without significant modification, safer for travel. Their adoption could be expected to free a greater proportion of available funds for the construction and maintenance of county highways if a decreased proportion were required to satisfy tort claims or for liability insurance.

## IDENTIFICATION OF THE PROBLEM

A survey of the counties in Iowa was undertaken in order to ascertain their experience with highway-related tort claims. This was accomplished in part by mailed questionnaires that solicited information from each county concerning any tort claims that resulted directly from the responsibility for construction and maintenance of highways, including the installation of traffic control devices.

Information was requested concerning any claims initiated during the period from January 1, 1973, to December 31, 1978. The questionnaires were directed to county engineers.

### Magnitude

Eighty-five completed questionnaires were received. Sixteen respondents indicated that no highway-related tort claims had been submitted during the period 1973 through 1978. The 14 counties that did not respond included four of the five most populous counties in Iowa.

Total highway-related tort claims reported by 85 counties amounted to $44 652 728 for the six-year reporting period. Annual totals are shown in Table 1. Note that the amounts claimed were relatively constant for the first five years of the reporting period. However, claims submitted during 1978 amounted to more than twice the annual average for the preceding five-year period. It is not apparent whether the 1978 claims experience is indicative of an increasing trend, although this appears to be the case, since the time series otherwise is relatively flat.

Of this total, claims of $26 339 108 (59.0 percent of the amount claimed during the six-year period) were pending at the end of 1978. A breakdown by category of claims submitted and pending is displayed in Table 2.

The total amount claimed resulted from 366 claims that were reported, an average of $122 002/claim. Most smaller claims tend to be settled quickly, so the average amount claimed for the 81 claims still pending at the end of 1978 was $325 174.

Payments on the 285 claims that had been settled by the end of 1978 amounted to $2 232 890. This was 12.2 percent of the $18 313 620 that had been claimed. Methods of settlement included denial of a claim in its entirety, full or part payment of the amount claimed, and, for most larger claims, by court-imposed judgment. Settlements by claims category are shown in Table 3.

By using the average amount claimed of more than $525 000 for the 85 counties that responded to the survey, the projected statewide total for 99 counties would exceed $52 million in total claims for the six-year period. A similar calculation for pending claims indicates that more than $30 million in claims was pending for all 99 counties at the end of 1978.

## Claims Categories

A description of typical incidents that were included in each claims category follows. However, note that an attorney for a plaintiff typically will employ a shotgun approach in the preparation of a case against a county defendent. The allegations often will include a wide variety of imperfections in signing and roadway geometrics. In such cases, the category was selected that appeared to be most relevant to the particular incident that gave rise to a claim.

### Inadequate Shoulder

Shoulder inadequacies reported by the counties as leading to tort claims were about equally divided between dropoffs at a pavement edge and other deficiencies. Dropoffs involved in such cases allegedly ranged from 3 to 12 in. Other problems included locations where the shoulder allegedly was soft, some material had eroded, or the shoulder otherwise was deficient in an unspecified manner.

### Improper Signing of Curve

Allegations of improper signing of curves tended to be general in nature, and simply charged a failure to provide adequate warning. In many instances, allegations were made of deficiencies in the design of a roadway as well as imperfections in signing.

Claimants generally referred to the Manual on Uniform Traffic Control Devices (MUTCD) (1) as the appropriate authority for signing practices. Depending on the signing actually in place, the alleged negligence might involve failure to use an advisory speed plate, a large arrow (or chevron) sign, or both.

### Railroad Crossing Sign

The usual allegation for claims against railroad crossing signs was that a county was negligent in failing to erect a stop sign or automatic signals at a railroad grade crossing. Impetus for these claims was afforded by the section of the Code of Iowa that suggests the appropriateness of stop signs at particularly dangerous crossings. However, a different basis was stated for the largest claim reported (for $3.5 million). Failure to install lights at the crossing was cited in this case to support an allegation of negligence by the county.

**Table 1. Annual amounts of tort claims in 85 Iowa counties.**

| Year | Total Amount ($) | Proportion of 1973-1977 Average |
|---|---|---|
| 1973 | 6 342 008 | 1.007 |
| 1974 | 3 910 961 | 0.621 |
| 1975 | 8 338 906 | 1.324 |
| 1976 | 7 934 128 | 1.259 |
| 1977 | 4 973 057 | 0.789 |
| 1978 | 13 153 668 | 2.088 |
| Total | 44 652 728 | |

**Table 2. Total and pending claims.**

| Category | Total Claims ($) | No. of Claims | Claims Pending at End of 1978 ($) | No. of Claims Pending |
|---|---|---|---|---|
| Inadequate shoulder | 7 966 540 | 17 | 2 686 500 | 8 |
| Improper signing of curve | 7 622 843 | 12 | 3 930 546 | 4 |
| Railroad crossing sign | 5 780 607 | 12 | 4 225 000 | 4 |
| Uncontrolled intersection | 4 930 251 | 10 | 4 926 051 | 9 |
| T-intersection | 3 822 165 | 17 | 3 532 776 | 10 |
| Rough road | 2 825 275 | 39 | 2 399 003 | 11 |
| Roadway geometric deficiency | 2 120 568 | 4 | 900 000 | 1 |
| Snow or ice on road | 1 462 000 | 10 | 768 500 | 5 |
| Improper signing for road closure | 1 375 661 | 8 | 375 000 | 1 |
| Mud on road | 1 350 000 | 4 | 0 | 0 |
| Bridge | 974 391 | 19 | 720 000 | 3 |
| Other | 4 422 427 | 214 | 1 875 732 | 25 |
| Total | 44 652 728 | 366 | 26 339 108 | 81 |

**Table 3. Ranking of categories by total amount of settlement.**

| Category | Total Settlement ($) | No. of Settlements | Amount of Original Claims ($) | Settlement Cost as Percentage of Claims |
|---|---|---|---|---|
| Improper signing of curve | 997 418 | 8 | 3 692 297 | 27 |
| Inadequate shoulder | 610 700 | 9 | 5 280 040 | 12 |
| Railroad crossing sign | 236 000 | 8 | 1 555 607 | 15 |
| Improper signing for road closure | 116 683 | 7 | 1 000 661 | 12 |
| Rough road | 58 842 | 28 | 426 272 | 14 |
| T-intersection | 50 264 | 7 | 289 389 | 17 |
| County vehicle accidents | 45 798 | 108 | 442 481 | 10 |
| Snow or ice on road | 45 000 | 5 | 693 500 | 6 |
| Gravel windrow and loose gravel | 30 588 | 28 | 669 480 | 5 |
| Construction signing | 10 439 | 8 | 61 048 | 17 |
| Road washout | 6 600 | 4 | 110 023 | 6 |
| Improper sign placement | 6 244 | 5 | 359 261 | 2 |
| Other | 18 314 | 60 | 3 733 561 | 0 |
| Total | 2 232 890 | 285 | 18 313 620 | 12 |

### Uncontrolled Intersections

Claims that involved uncontrolled intersections involved allegations that counties were negligent in failing to provide stop controls at intersections. If two-way stop control had been provided, a need for four-way stop control was alleged. Such claims may also be accompanied by assertions that other problems existed, such as deficiencies in the designs of the intersecting roadways. On paved highways, some claims also alleged a need for rumble strips.

### T-Intersection

Most of the claims against T-intersections involved alleged deficiencies in the signing needed to provide sufficient warning at T-intersections. An advance warning sign, a large arrow sign on the far side of an intersection, or both most frequently were at issue. However, both of the claims in this category for more than $1 million resulted from accidents at stop-controlled T-intersections. The reflective quality of the stop sign was at issue in both cases.

### Rough Road

Many of the claims due to rough roads merely stated that the road was rough. Other allegations included frost boils, potholes, or blowups on portland cement concrete pavement.

### Roadway Geometric Deficiency

Roadway geometric deficiencies include four claims that alleged an excessively steep grade or inadequate sight distance on a curve or excessive crown on a road. Note that allegations that involved the width of a roadway have been included in a separate category on narrow roads.

### Snow or Ice on Road

Claims due to snow or ice on the road resulted from accidents allegedly caused because snow or ice was on the roadway. Counties in these cases allegedly were negligent either for failure to remove snowdrifts or by failing to correct slippery conditions caused by ice or packed snow.

Most of these claims arose due to snow or ice accumulations from precipitation. All of the claims of this nature that had been settled resulted in no payment to the claimants. The one case that resulted in payment to several claimants came about because ice accumulated on the roadway due to runoff from adjacent land.

### Improper Signing for Road Closure

Of eight claims due to improper signing for road closure, four were for minor damage that occurred when automobiles or light trucks struck part of the signing or barricades used to close a road. One large claim arose when a motorcycle struck a barricade that was used to close a road. The barricade allegedly did not conform with standards. The other three cases alleged that a road should have been closed but was not. In two instances, a bridge had washed out and in the other case some construction activity was taking place.

### Mud on Road

The four claims due to mud on the road resulted from the same incident. A vehicle on a paved county highway encountered a road section that was slippery due to the presence of mud and skidded out of control. A jury trial resulted in a verdict in favor of the defendent county.

### Bridges

Most claims against bridges have been small demands to cover vehicle damage. They generally resulted from roughness of deck, often a timber deck. However, four claims, as follows, have been for substantial amounts:

1. Bridge deck allegedly slick from frost,
2. Collapse under the load of a truck,
3. Accident allegedly resulted from loss of control due to dip in the bridge approach, and
4. Approach fill undermined and gave way beneath a vehicle.

### Improper Sign Placement

Improper sign placement was included to encompass alleged signing deficiencies not included in the categories of curves, railroad crossings, T-intersections, road closures, or construction activities. Most such claims involved stop signs that either were obstructed or were missing as a result of vandalism.

Among other claims, the largest alleged failure to install a pedestrian crossing sign. One claim resulted because no advance-warning sign was used before a stop. Another alleged that a county was negligent because a no-passing zone had not been established.

### Gravel Windrow and Loose Gravel

Most of the claims due to gravel windrow and loose gravel involved vehicle damage only, although a few involved accidents that had personal injuries. They resulted when a vehicle either struck the gravel windrow that occurred during blading of a loose-surfaced road or encountered loose gravel that allegedly had not been sufficiently spread or hit a large stone lying on the road. One claim of a different nature arose when crushed stone from the shoulder had encroached onto the edge of the pavement and caused loss of control of a vehicle on a curve.

### County Vehicle Accidents

Claims resulting from motor vehicle accidents were not included in the responses to the survey unless they occurred when a county vehicle was actually engaged in a construction or maintenance activity. Consequently, most of the claims in this category resulted from accidents that involved graders or snow plows. Fewer of the accidents that gave rise to these claims involved trucks, mowers, or heavy equipment. Included are accidents that resulted in damage to other vehicles as well as to other types of property.

### Construction Signing

Construction signing includes claims that resulted from alleged deficiencies in warning of construction or maintenance (other than routine blading) activities on the road other than those that involved signing for road closure.

The largest claim resulted when a worker sealing cracks on a resurfacing project was struck by a passing automobile. Three claims involved vehicles running into excavations. Other claims resulted from accidents that involved an automobile that

Table 4. Description of dependent and independent variables.

| Variable | Definition | Mean Value | Simple Correlation with Y |
|---|---|---|---|
| Y | Total dollar amount of claims for a county from 1973 through 1978 | 525 326 | 1.000 |
| $X_1$ | Latitude of the county seat of a county, minus 40° | 2.04 | 0.215 |
| $X_2$ | Longitude of the county seat of a county, minus 90° | 3.46 | -0.153 |
| $X_3$ | County population based on the 1970 census | 22 250 | 0.244 |
| $X_4$ | Miles of loose-surfaced and unsurfaced roads in a county's secondary road system in 1977 | 752 | -0.034 |
| $X_5$ | Miles of hard-surface roads in a county's secondary road system in 1977 | 136 | 0.093 |
| $X_6$ | Total road mileage in a county's secondary road system in 1977 | 888 | 0.002 |
| $X_7$ | Number of attorneys in a county that are members of the Iowa State Bar Association in 1978 | 27.5 | 0.195 |
| $X_8$ | Vehicle miles traveled per day on a county's secondary road system in 1977 | 87 515 | 0.206 |
| $X_9$ | Average value in dollars per acre of agricultural land in a county in 1978 | 1634 | 0.091 |
| $X_{10}$ | Population in county that resides in communities of at least 1500 in 1970 | 12 587 | 0.214 |
| $X_{11}$ | Population in county that resides outside communities of 1500 or more in 1970 | 9663 | 0.317 |

struck a bituminous paving machine, a motorcycle that skidded on a bridge deck after it was treated with linseed oil, and an automobile that struck the end of culvert pipe lying on the shoulder.

### Narrow Road

Four claims were placed due to narrow roads. Two claims resulted from accidents on roads that allegedly had become too narrow due to erosion of one edge of the road. One of these was occasioned when a farm tractor rolled into the ditch and killed the operator.

The other two cases apparently involved roads that had retained their design widths. One was occasioned by an accident on a bridge that was 20 ft wide. The other claim followed an accident on a dirt road that allegedly was too narrow for two vehicles to meet safely.

### Water Backup or Right-of-Way Encroachment

Water backup or right-of-way encroachment includes claims that arose from highway construction or maintenance activities that in some manner interferred with the property right of adjacent land owners. In four cases, construction of a drainage facility allegedly caused water to back up on adjacent land. In two cases, trees on private property were cut down without the owner's consent. The other two cases involved encroachment of a roadway onto private property.

### Road Washouts

In each of four claims, a road allegedly had washed out to cause an accident that gave rise to the claim. Note that some of the claims that involved shoulder deficiencies, road closure signing problems, and narrow roads also involved erosion of some part of a roadway. Claims in this category differ, in that each incident affected the traveled portion of the road and the principal allegations concerned warning of a hazard rather than road closure.

### Unclassified

Three sizable claims could not be included in other claims categories. These included a work area accident that involved a fatal injury to a contractor's employee, a claim after a house fire to which access by fire equipment was hampered because the county had a bridge under repair, and a claim that arose from a collision between an automobile and a post placed on the road shoulder to support a box used for newspaper delivery.

### Other Maintenance Activities

Other maintenance activities involved only comparatively small claims, including damages from weed spraying or tree trimming and from gravel that blew from trucks and damaged passing or following vehicles.

## Analysis of Claims Experience

A multiple-regression analysis was undertaken in order to identify any demographic or geographic factors that tended significantly to explain the variation in claims experience among counties. Two different dependent variables were tested--the total amount of claims reported for a county during the period 1973 through 1978 and the claims per capita for this period.

No useful insight into the occurrence of tort claims in a specific county was afforded by this statistical analysis. None of the correlations of explanatory variables with the amount of claims was sufficiently high to indicate that any of these variables was useful for predicting claims experience. Equations developed by using multiple-regression techniques also lacked significant explanatory capability. These findings suggest either that the occurrence of tort claims is almost completely random or that factors to explain their occurrence remain to be identified.

A list of the independent variables tested is given in Table 4. Also shown in Table 4 are the mean values for each variable and the simple correlation between that variable and the total claims during the six-year study period.

An additional analysis, by using a sample of only 11 counties, used as an independent variable a subjective rating that was based on the extent to which a county's signing practices appeared to go beyond the minimum requirements set forth in MUTCD. A significant inverse relation was shown between claims experience and the extent to which use of warning signs apparently exceeds the requirements of MUTCD. Because of the small sample size and the highly subjective nature of the rating variable, caution is necessary in the interpretation of this finding. Also note that this research did not demonstrate a relation between the degree of safety afforded the traveling public and either signing practices or the amount of claims. It is quite possible that safer highways may attract more claims than will older, less safe highways.

## INTERVIEWS WITH COUNTY ENGINEERS

Information to supplement that afforded by the questionnaires was obtained by interviews in varying depth with 40 county engineers. Fifteen of these interviews were in sufficient depth to cover most or all of the following topics:

1. Claims reported on the questionnaire responses,
2. Procedures for maintaining loose-surfaced and unsurfaced roads,
3. Policies regarding coordination of efforts on county line roads,
4. Policies about use of stop control,
5. Use of speed limits outside cities,
6. Use of lighting at rural intersections,
7. Practice with respect to accident reporting,
8. Sign inventory,
9. Practice with respect to use of warning signs, and
10. Use of advisory speed plates.

Counties in Iowa are divided into maintenance districts for routine blading and snow removal on loose-surfaced and unsurfaced roads. A grader with operator is assigned to each district. Data from 14 counties indicated a range of from 7 to 21; the average was 11.4 graders per county. Graders normally worked singly and covered most roads in their districts in four- or five-day cycles. It was not uncommon for a grader to work in a lane in the direction opposite to the normal flow of traffic.

Approaches to coordination of maintenance activities on county line roads varied widely among the counties in which interviews were conducted. Similar problems were also reported at state lines and municipal corporation boundaries. Formal agreements that were legally approved by resolutions were much less common than were informal agreements among county engineers. Agreements always covered routine maintenance operations such as blading, snow removal, and mowing but infrequently spelled out responsibility for signing. Several examples were noted of potentially serious discrepancies or omissions in traffic control on county line roads. Most of these involved different policies among counties that occasioned incónsistencies with respect to stop control.

Counties most frequently used stop control to afford preferential treatment to through highways, generally paved roads on the trunk system. Other installations of stop signs were based on studies by county engineers, usually rather informal, that considered traffic volumes, sight distances, accident experience, composition of the traffic streams, and other factors as appropriate. Many such studies were initiated in response to suggestions from private citizens.

The only instances of speed limits on county roads reported by the county engineers who were interviewed were in built-up areas. These included roads in incorporated communities, unincorporated communities, and rural subdivisions. Speed limits were implemented on the basis of traffic engineering studies carried out by personnel of the Iowa Department of Transportation.

Practices among counties varied widely with respect to the use of roadway lighting. Lighting was not used on county road systems in a majority of the counties visited. Usage in four counties that had installed lights varied from 6 to 27 locations. Most installations consisted of a single luminaire at an intersection. Two lights were used at a few locations. Economic constraints and the threat of vandalism were the reasons most frequently given for not using more lights at county road intersections.

Eight of the 14 county engineers with whom this topic was discussed indicated that they seldom or never were notified of an accident on a county road that was investigated by the sheriff's office. Four others stated that they were usually notified and two thought that they were made aware of virtually all accidents investigated by the sheriff. In no case could a county engineer anticipate notification of an accident if the investigating officer was from the state patrol. No other mechanism exists for timely notification to county engineers of accidents that may result in tort claims against counties.

Each county engineer interviewed reported the existence of some form of sign inventory for the county. These varied widely in complexity and format. Most inventories consisted of a series of maps, each usually covered a single township, on which signs were located. Some detail as to sign type and condition was afforded by a symbol, number, or series of numbers on the maps. Other inventories were on cards or forms prepared for this purpose. One county was in the process of implementing a computerized sign inventory. The most common procedure for updating an inventory was a semiannual or annual visual inspection of signs on the entire county highway system by a person designated to have primary responsibility for signing.

Philosophies regarding the use of signs varied widely among the county engineers who were interviewed. These differences were manifested most clearly with respect to the use of warning signs. About half of these engineers favored adherence to the minimum requirements set forth in MUTCD. The others clearly went beyond these minimum requirements in varying degrees by using more warning signs than strict adherence to MUTCD would suggest. There generally were pronounced differences in the elaborateness of signing, depending on the highway type. Advance warning signs of all types tended to be used much more frequently on paved roads that had high volumes than on unpaved roads that carried very low traffic volumes.

Similarly, advisory speed signs were rarely used on unpaved roads by the interview responses. Use of these signs was much more common on paved highways. The appropriate advisory speed generally was determined by trial runs to determine a speed that precludes sliding and feels comfortable. A ball bank indicator reportedly was used to assist in this process by only two of the county engineers who were interviewed.

A critical concern for vandalism of traffic signs and hazard markers was expressed by all of the county engineers who were interviewed. Loss of these devices not only has caused a substantial expense to the counties for replacement but also has been the cause of a number of accidents and led to several tort claims.

An appropriate response to the destruction of traffic signs has been difficult to formulate, according to the county engineers who were interviewed. Some county engineers reported success with information campaigns that made an appeal to the public and pointed out the hazards and expense occasioned by vandalism of signs. Others found such campaigns counterproductive. The directing of attention to the problem apparently attracted more imitators than it deterred. Similar experience was reported regarding vigorous prosecution and punishment of those apprehended after destroying traffic signs. The rather nominal fines received by offenders and the resultant publicity was often believed to lead to more sign destruction and to have no deterrent effect.

Unfortunately, the problem of vandalism appeared clearly to inhibit the more extensive use of warning signs. County engineers, in general, wanted to minimize their exposure to vandalism by reducing the number of signs.

Most of the county engineers who were interviewed regularly investigated accidents that occurred on county roads and were reported to them. They documented the facts related to possible causes of the accidents, including measurements of marks left by the vehicle or vehicles involved. They also took photographs of road conditions and control devices. In several instances these photographs were the critical items of evidence in sustaining the denial of a tort claim that had been based on erroneous facts.

SUMMARY AND CONCLUSIONS

The threat of tort claims that result from alleged highway defects introduces an additional concern to those charged with providing highway service. Any decision related to highway design, construction, or maintenance made by a jurisdiction that does not enjoy sovereign immunity is subject to possible review in court. There, the good faith and competence of the decision maker will be carefully scrutinized and challenged.

The results of this research suggest that the possibility of such a review may induce responses that are entirely defensive in nature and may even exert an adverse effect on the safety and efficiency of highway travel. At least this seems to be the case with county governments in Iowa. The installation of stop signs at low-volume rural intersections or railway grade crossings is an example of a response that has introduced inefficiencies in travel and with little or no beneficial effects on safety.

Given the fiscal constraints within which county highway systems are constructed and maintained, their more consequential imperfections cannot be corrected. Moreover, considerable evidence shows that current levels of expenditures for highways reflect the viewpoint of a majority of citizens regarding the value of highway safety. The public has demonstrated little willingness to support substantially increased outlays for safety measures on local highway systems. Instead, low-cost responses, such as improvements in highway signing, need to be sought out and implemented. An additional element of risk analysis, which results from tort claims, must be entered as a variable in making a choice among alternatives to establish priorities for highway improvements.

A study of Tables 2 and 3 will provide some insight into the relative risk of tort claims for various problem areas. The data in Table 2 indicate that only five claims categories have accounted for 67 percent of the total amount of claims. However, as shown in Table 3, not all types of claims offer the same probability of recovery.

Approximately 56 percent of the highway-related claims submitted to 85 counties in Iowa during the period 1973 through 1978 related directly to traffic control and signing practices. An additional 40 percent related to roadway deficiencies of such nature that a lack of adequate warning could support an allegation of negligence against a county. Thus, proper signing practices could afford at least a partial defense for 96 percent of the amount of claims received.

As part of this research, two alternative methods were tested for routine blading operations on loose-surfaced and unsurfaced roads. In one method, two machines would work in tandem. In the other method, a grader would reverse direction at each intersection. The objective of each method is to minimize the length of exposed windrow. A simulation based on representative maintenance districts showed that both methods would increase machine working time by 15 percent or more and would introduce additional hazards sufficient to offset the safety advantage of shortened windrows.

The study also included a series of trial runs to test the suitability of using a ball bank indicator to establish advisory speeds on curves on loose-surfaced roads. Considerable variation in indicator readings was noted due to differences in vehicle suspensions, surface roughness, and the lack of uniformity in road cross sections. Although the ball bank indicator can assist in establishing advisory speeds on curves on loose-surfaced roads, this variation suggests that engineering judgment is essential for properly interpreting the results of such trial speed runs.

RECOMMENDATIONS

1. Follow strictly the provisions of MUTCD in the use of warning signs. A defense against many highway-related tort claims can be afforded by demonstrating that warning signs were used in a suitable manner to provide motorists with notice of an unusual or potentially hazardous condition. Although MUTCD contains relatively few mandatory requirements with respect to warning signs, the existence of such a mandate is often inferred in court when the failure to install a warning sign becomes the matter at issue. Consequently, adherence to the minimum requirements of the manual is essential to avoid a finding of negligence against a highway authority. Moreover, courts often have held that even strict adherence to MUTCD is insufficient to demonstrate reasonable care in the provision of highway service.

2. Establish a coherent and carefully documented policy governing the use of stop signs. A policy should be adopted that sets forth specific circumstances that call for the installation of stop signs. Criteria governing their use should be consistent with those suggested in MUTCD, including accident experience, approach speeds, sight distance, and traffic volumes. An engineering study should be conducted and appropriately documented for each installation and for each instance where stop sign control is shown to be inappropriate.

3. Establish a continuing sign inventory process. A sign inventory is essential to provide evidence of the existence of a particular sign at a particular location at a specific time. It also provides a convenient mechanism for evaluating sign use for conformance with standards. The inventory process should be continuous with constant updating as signs are added, removed, or replaced.

4. Establish written agreements to cover roads on jurisdictional boundaries. Written agreements are necessary to establish responsibility for maintenance and for liability on roads at the boundaries of highway jurisdictions. The responsibility for signing should be spelled out in detail. Regulatory controls should be implemented by appropriate actions from both governing bodies.

5. Use a ball bank indicator to establish advisory curve speeds where needed. The appropriate advisory speed on a curve should be established by trial runs by using a ball bank indicator to demonstrate the combined effect of centrifugal force and superelevation. However, because of variations in vehicle suspensions and other factors, adherence to numerical limits must be tempered by judgment to ensure that the advisory speed does not closely approach the speed of incipient sliding or cause a feeling of discomfort to a driver within the curve.

6. Establish a road and sign inspection program. Many claims result from temporary conditions, such as roadway damage from a flash flood, surface irregularities, or accumulations of water from thawing or sign vandalism. A systematic method of notification of such conditions should be established by using assistance from the general public as well as highway department workers and other pub-

lic employees who travel regularly within the jurisdiction.

7. Establish a program to document conditions that surround highway accidents. The ability to defend a tort suit often depends on evidence that may be difficult to establish several years after a highway accident when a claim may reach the settlement stage. Evidence should be gathered immediately following an accident by a person knowledgeable about the highway facility. Such evidence, which should include photographs, should document the condition of the highway and traffic control devices as well as information that may be needed to reconstruct an accident.

8. Develop procedures to ensure timely notification of highway accidents. Immediate documentation of the conditions that surround an accident obviously is dependent on timely notification of accidents likely to result in tort claims. Arrangements should be made with the appropriate law enforcement agencies to ensure that the highway agency receives such timely notification.

ACKNOWLEDGMENT

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REFERENCE

1. Manual on Uniform Traffic Control Devices. AASHTO, Washington, DC, 1978.

*Publication of this paper sponsored by Committee on Traffic Safety in Maintenance and Construction Operations.*

# Procedure for Evaluating Efficiency of Power-Operated Cutting Tools in Localized Pavement Repair

**H. RANDOLPH THOMAS AND DAVID A. ANDERSON**

**This paper describes a procedure for evaluating the cutting efficiency of air- and gasoline-operated pavement breakers. The procedure was developed as part of a comprehensive study of the pothole-repair procedures used by the Pennsylvania Department of Transportation. Cutting times and delay times are recorded by using the stopwatch study technique and time-lapse photography. A stepwise linear-regression-analysis procedure is used to determine the significant variables, and this information is subsequently used to compare cutting performance. Cutting times in minutes per cubic meter and most probable cutting time in minutes are used as the basis for further comparisons. Management delays are documented for duration and type for both cutting tools. These productivity efficiency factors are then used to show that the air-operated hammer is approximately 25 percent more productive than the gasoline-operated hammer. A procedure is demonstrated that applies the unit cutting rate and the productivity efficiency factor to establish a reasonable productivity goal or to verify an existing productivity or performance standard.**

There is little doubt regarding the importance of proper equipment selection in the development of an efficient and productive construction or maintenance operation. All organizations that routinely deploy and use construction equipment are keenly interested in the selection of the right equipment to do the job. Examples of such organizations include contractors, owners who perform force-account construction and maintenance, and state departments of transportation.

Much has been written about the selection of heavy construction equipment, such as cranes, dozers, scrapers, and trucks (1-3). Typically, criteria are presented to help the user decide whether to rent or purchase, and the decision is largely one of economics. In determining the applicability of the equipment to perform the given task, the key reference source is often the manufacturer's specifications and performance characteristics (4).

The procedures noted above have two important shortcomings. First, they are applicable to high-cost, specialized pieces of equipment intended primarily for the earth-moving contractor. Little guidance is available for evaluating the more common pieces of construction equipment, such as an air compressor. Second, for hauling equipment, the production characteristics are reasonably well defined by the manufacturer. Thus, handbooks provide the contractor with the needed information for evaluating equipment based on an approximate productive output. Unfortunately, production rates for smaller pieces of construction equipment cannot be determined, except by trial evaluations, because productivity is primarily established by (a) the operator, (b) field conditions, and (c) the effectiveness of management. These factors are not addressed by the literature available from the equipment vendor. As pointed out in a recent Value Engineering study of bituminous patching operations, there is a need for further study and evalution of mechanical cutters, tampers, and compactors and a comparison with current methods (5).

## OBJECTIVE AND SCOPE

The objective of this paper is to describe a systematic procedure for evaluating the cutting efficiency of air- and gasoline-operated pavement breakers. The important aspects related to cutting performance, field conditions, and management will be considered. A second objective is to assess the significance of the condition of the cutting bit relative to performance. This information is useful to the manager in planning a bit-sharpening program. The final objective is to demonstrate how field evaluation data can be used to establish a reasonable productivity goal or to verify an existing productivity or performance standard.

The procedures presented in this paper were developed during a comprehensive research study of the pothole-repair strategies used by the Pennsylvania Department of Transportation (6). This study encompassed an evaluation of management practices, pothole-repair procedures, materials, and craft productivity, equipment needs, and applicability. The portion of this study reported here is limited to the evaluation of the pavement-breaker type cutting tools used for removing distressed material from asphaltic concrete pavements. Both flexible-base asphaltic concrete and overlaid portland cement concrete pavements were studied. The equipment that was studied included gasoline-operated Pionjär, model-120 pavement breakers and air-operated jackhammers powered by air compressors. The compressors can be divided into two groups. The first group consists of a number of older model compressors owned by the department. This equipment is characterized by its age, which means that maintenance is a continual problem. These compressors have only a single-line capability, meaning that only one tool may be operated at a time. The second group includes new compressors, both those rented and owned by the department. These are characterized by two- and three-line capability. Compressors in the first group are in the 0.040 $m^3$/s (85 $ft^3$/min) class. Compressors in the second group are in the 0.082 $m^3$/s (175 $ft^3$/min) class.

## DATA COLLECTION

An evaluation of equipment performance characteristics and worker use factors requires the measurement of (a) cutting times and (b) delay times associated with the cutting operation. These data were gathered by using time-lapse photography and stopwatches. In addition, the physical dimensions of each hole were documented, including the depth at key locations and the layout of the cut area. By using the dimensions of the holes, areas, and volumes, unit cutting rates were calculated. Other data that were gathered included the condition of the cutting bit, hammer weight, type of pavement, and the pavement condition.

A total of 13 patching operations were studied, which comprised 116 potholes. These holes were located on 12 legislative routes in four counties in central and western Pennsylvania. Seventy-six holes were repaired in asphaltic concrete pavements and 40 were repaired in composite pavements (asphaltic concrete over portland cement concrete). Equipment used for cutting included Pionjär, model 120; gasoline-powered breakers; and air compressors. The Pionjär weighted 26 kg (57 lb). The air-operated hammers were observed in three weight classes--27, 34, and 41 kg (60, 75, and 90 lb). Six crews used the Pionjärs, and seven crews used air compressors. The Pionjärs were essentially new; however, five of the seven compressors studied were old. Two new Ingersoll-Rand compressors were observed. One, which was owned by the Pennsylvania Department of Transportation, had three-line capability, and the other rented compressor had two lines.

## DATA ANALYSIS

The effective deployment and use of pavement-cutting equipment requires that the manager understand the significance of those variables that affect cutting performance. The identification of factors was done by using the statistical analysis system (SAS) that is available from the SAS Institute (7). A stepwise linear-regression-analysis procedure with the MAXR option was used on the Pennsylvania State University IBM model 370 computer. The MAXR option provides the capability of looking at essentially all possible regression combinations, because multiple models are evaluated at each level and the best model is selected.

### Significant Factors

The stepwise linear-regression analysis was performed with cutting time in minutes as the dependent variable and the independent variables described below. The data were obtained as part of the stopwatch study.

1. Two types of equipment were considered--air compressors and Pionjär;
2. Breaker bits were classified as sharp, intermediate, and dull;
3. Cutting operations were limited to asphaltic concrete and composite pavements;
4. Pavement condition was classified as either sound or distressed (obviously a distressed condition is associated with a pothole; however, for this study, pavement was considered sound if surrounding material remained reasonably intact as the cutting edge was applied; a pavement that had essentially lost most of its life and seemed to fall apart under the action of the cutting tool was considered distressed; the distressed condition was limited almost exclusively to those holes along the edge of the roadway);
5. Hole depth;
6. Holes lying along the edge of the pavement were usually cut along only three sides;
7. Hole area; and
8. Hole volume.

The results of the regression analysis indicated that a four-variable regression equation that has an $R^2$ value of 0.81 was the best model. Significant variables in this equation were (a) hole volume, (b) type of equipment, (c) interaction between equipment type and pavement type, and (d) interaction between equipment type and pavement condition.

Surprisingly, the most significant variable is the volume of the hole. Figure 1 shows that hole size is noticeably skewed toward smaller-sized holes; however, note that almost 14 percent of the holes have volumes in excess of 0.23 $m^3$ (7.99 $ft^3$). One may wonder whether such large holes should even be defined as potholes. Hole volume may seem unimportant to the manager, who has little prior knowledge of the size holes to anticipate. Nevertheless, hole volume is very important to the engineer, who must evaluate various types of cutting equipment. Subsequent analyses will be done on the basis of data related to hole volume.

Figure 2 shows the relationship between actual cutting times and hole volume. The regression equations for the air compressor and the Pionjär are shown. A measurable difference between cutting rates can be observed. While this difference is widely accepted throughout the industry, the magnitude of the differential is generally not known. By using the regression equations for an average hole volume of 0.10 $m^3$ (3.52 $ft^3$), as determined from Figure 1, the likely mean cutting time for the air compressor and the Pionjär is 4.39 and 6.79 min, respectively. The difference between cutting rates is discussed below in greater detail.

### Comparison of Equipment

The numerical comparison of cutting performance is very important to the manager because the rate at which holes are cut and prepared establishes the production rate of the crew. Figure 2 shows the

**Figure 1. Distribution of holes according to approximate hole volume.**

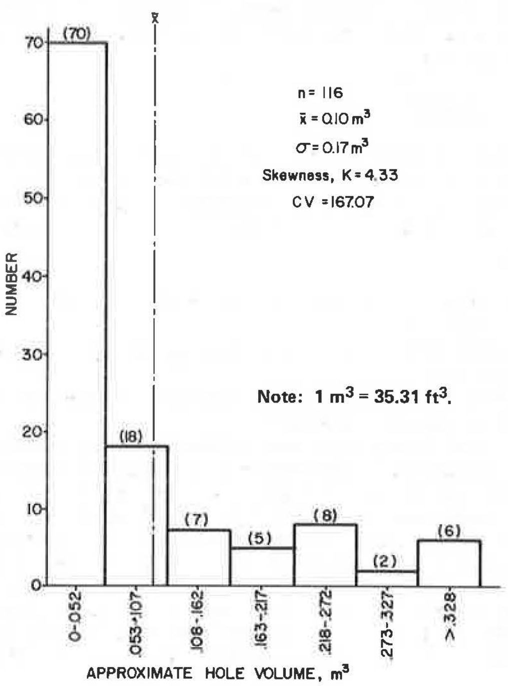



**Figure 2. Plot of cutting time versus hole volume.**

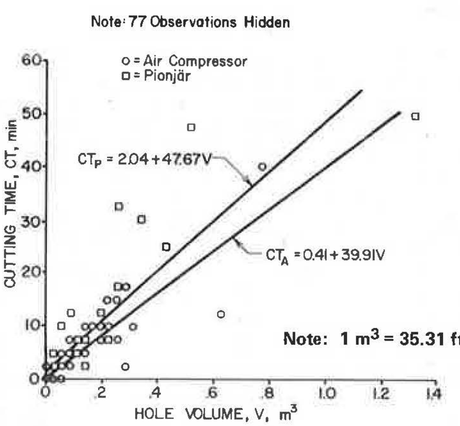



**Figure 3. Frequency histogram of cutting rate.**

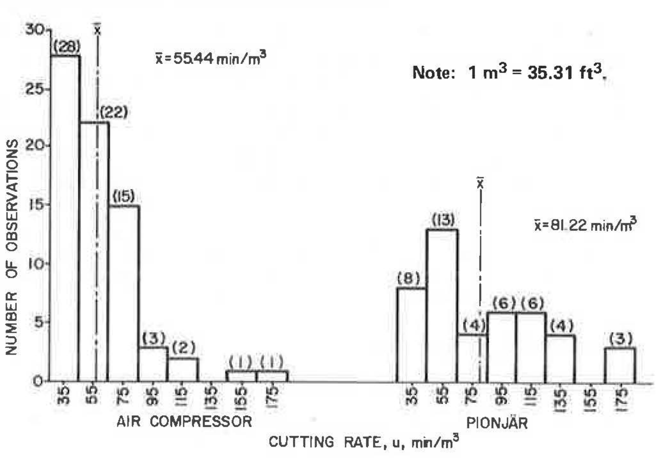
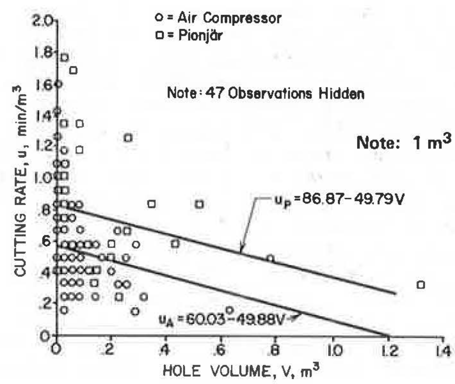



**Figure 4. Plot of cutting rate versus hole volume.**




plot of cutting time versus hole volume and the anticipated difference in mean cutting times for the air compressor and the Pionjär. The difficulty in using these values as the basis for comparison is that the distribution of hole volumes is definitely skewed toward smaller-sized holes. Furthermore, approximately 14 percent of the hole volumes are very large [i.e., exceed 0.23 $m^3$ (7.99 $ft^3$)]. Since the cutting time differential widens significantly as the hole size increases, concerns should be raised about use of the approach shown in Figure 2 as a predictor of relative performance. Note also that the holes prepared by the Pionjär tended to be larger than those cut by the compressor. This information is summarized below (note 1 $m^3$ = 35.3/$ft^3$).

| Item | Compressor (%) | Pionjär (%) |
|---|---|---|
| Percentage of holes exceeding 0.10 $m^3$ | 19.4 | 31.8 |
| Percentage of holes exceeding 0.14 $m^3$ | 16.7 | 20.5 |
| Percentage of holes exceeding 0.28 $m^3$ | 5.6 | 9.1 |
| Maximum volume ($m^3$) | 0.77 | 1.30 |

The use of an average size hole of 0.08-0.11 $m^3$ (3-4 $ft^3$) should also be questioned because the probability of observing such a hole is relatively small ($p = 0.06$). What is needed is a measurement of total performance for cutting all sizes of holes, not just a typical hole.

Unit cutting rates are next examined as a possible measure of performance. The distribution of unit rates is shown in Figure 3. The average cutting rate for the air compressor and the Pionjär is 55.4 min/$m^3$ (1.57 min/$ft^3$) and 81.2 min/$m^3$ (2.30 min/$ft^3$), respectively. These mean rates suggest that the Pionjär will require approximately 47 percent more time than an air compressor to cut a hole of equivalent size. However, once again, there should be concern over how the unit rates are affected by hole size. As can be seen in Figure 4, the unit rate for each type of equipment decreases as hole size increases.

The most appropriate measure of performance is the probable cutting time or weighted average. This parameter accounts for the fact that (a) all hole sizes will be encountered, (b) the distribution of hole size is skewed, and (c) the unit rates in minutes per cubic meter are uniquely described for each equipment type and hole size. The procedure for computing probable cutting time uses the following equation:

Table 1. Probable cutting time.

| Interval, i | Lower Class Limit ($m^3$) | Upper Class Limit ($m^3$) | Probability of Occurrence, $P_i$ | Avg Volume, $V_i$ ($m^3$) | Avg unit Rate, $u_i$ (min/$m^3$) Air Compressor | Pionjär | $P_i \times V_i \times u_i$ (min) Air Compressor | Pionjär |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.00 | 0.052 | 70/116=0.603 | 0.025 | 58.62 | 85.46 | 0.88 | 1.29 |
| 2 | 0.053 | 0.107 | 18/116=0.155 | 0.077 | 56.15 | 82.99 | 0.67 | 0.99 |
| 3 | 0.108 | 0.162 | 7/116=0.060 | 0.136 | 53.33 | 80.16 | 0.44 | 0.65 |
| 4 | 0.163 | 0.217 | 5/116=0.043 | 0.195 | 50.15 | 76.99 | 0.42 | 0.65 |
| 5 | 0.218 | 1.416 | 16/116=0.138 | 0.410 | 39.55 | 66.39 | 2.24 | 3.76 |
| Total | | | | | | | 4.65 | 7.34 |

Note: 1 $m^3$ = 35.31 $ft^3$.

Table 2. Analysis of delay times for cutting operations.

| Activity | Frequency of Occurrence | Stopwatch Study Number: Air Compressor 1 | 2 | 3 | Pionjär 4 | 5 | 6 | Total No. | Percent |
|---|---|---|---|---|---|---|---|---|---|
| NWTA[a] | | 124.32 | 80.72 | 47.16 | 128.99 | 149.35 | 40.31 | 570.85 | |
| Cutting time | | 71.70 | 62.31 | 40.02 | 118.19 | 124.25 | 19.60 | 436.07 | 76 |
| Delay time | | | | | | | | | |
| Traffic | 11 | 0.71 | | | 1.04 | 1.27 | | 3.02 | 2[b] |
| Change hammers | 1 | 2.30 | | | | | | 2.30 | 2 |
| Clean hole with shovel | 8 | 0.51 | 2.77 | | | 13.08 | | 16.36 | 12 |
| Clean hole with air compressor | 28 | 48.38 | 7.47 | 7.02[c] | | | | 55.85 | 41 |
| Change operators | 6 | | 2.02 | 0.54 | | 0.68 | | 3.24 | 2 |
| Instructions | 13 | 0.51 | 3.17 | | | | | 3.68 | 3 |
| Personal | 17 | | 2.98 | 0.41 | 1.35 | 4.15 | 18.85 | 27.74 | 21 |
| Move to new hole | 31 | 0.21 | | 6.19 | | 1.83 | 0.45 | 8.68 | 6 |
| Refuel Pionjär | 9 | | | | 8.41 | 3.50 | 1.41 | 13.32 | 10 |
| Adjust equipment | 1 | | | | | 0.59 | | 0.59 | 1 |
| Total | | 52.62 | 18.41 | 7.14 | 10.80 | 25.10 | 20.71 | 134.78 | 24 |
| Efficiency[d] | | 58 | 77 | 85 | 92 | 83 | 47 | 76 | |

[a]NWTA = Net work time available is the total study time less time spent on coffee breaks, major equipment breakdown, etc.
[b]Percentages for delay times are expressed as a percentage of the total delay time.
[c]The cleaning time is not included in the total delay time because a dual-line compressor was used that permitted cutting to continue without interruption.
[d]Efficiency = (Cutting time/NWTA) x 100.

$$CT = \sum_{i=1}^{n} P_i V_i u_i \quad (1)$$

where

CT = most probable (weighted average) cutting time (min),
$P_i$ = probability of encountering a hole whose volume is within a specified class interval (i),
n = number of classes into which the distribution of hole volumes is divided,
$V_i$ = average volume ($m^3$) of those holes located within interval i, and
$u_i$ = average unit rate (min/$m^3$) for those holes located within interval i.

The distribution of hole sizes shown in Figure 1 was divided into five intervals. The probabilities ($P_i$) and the average volume within each interval ($V_i$) were computed by using actual hole data. By using $V_i$, the unit rates can be determined from the regression equation in Figure 4. The calculations necessary for the application of Equation 1 are summarized in Table 1, from which the probable cutting times are computed to be as follows:

Probable cutting time for air compressor = 4.65 min/$m^3$ and
Probable cutting time for Pionjär = 7.34 min/$m^3$.

It would appear then that a relative comparison of the two cutting tools will favor the air compressor by a considerable margin because the Pionjär requires approximately 58 percent more time to cut a group of holes that are distributed as per Figure 1.

## Significance of Bit Condition

In addressing the question of the significance of bit condition to cutting performance, only data for the Pionjär and the 27-kg (60-lb) class air hammers were considered. This was done to minimize any possible bias introduced because the data gathered for the 34-kg (75-lb) and 41-kg (90-lb) class hammers were from only one roadway. The remaining data were statistically unbalanced because there were no dull bits for the compressor or intermediate bits for the Pionjär observed. Therefore, it was felt that a regression equation developed from the data would not be reliable.

To assess the significance of bit condition, only the Pionjär data were reviewed. The average unit rate in minutes per cubic meter was determined for sharp and dull bit conditions. Twenty-six holes were prepared, at an average rate of 69.6 min/$m^3$ (1.97 min/$ft^3$), by using a sharp bit. A dull bit was used on the remaining 18 holes. The average unit rate was 97.8 min/$m^3$ (2.77 min/$ft^3$), which is approximately 41 percent greater than the rate for the sharp bit. Although more studies need to be conducted, an intensive bit-sharpening program would appear to be justified.

Management Practices

To evaluate management effectiveness relative to the cutting operation, the delay times recorded during six stopwatch studies were identified by magnitude and type. These are shown in Table 2. Studies 1, 2, and 3 are of air compressors, and studies 4, 5, and 6 are of the Pionjär. As can be seen, approximately 76 percent of the net work time available (NWTA) was spent in actually cutting the holes. NWTA is defined as the time available that actual cutting can take place after coffee breaks, travel time, major equipment failures, and so forth have been excluded. The delay time (24 percent) is primarily attributed to (a) cleaning the hole with compressed air (air compressor only), (b) personal breaks, (c) waiting for the hole to be cleaned via shovel, and (d) equipment refueling (Pionjär only). A number of the categories where ineffective time can be minimized relate directly to the ability of the foreperson to manage work by the crew. For example, in study 2 it would appear that, by properly marking the cut area around the hole, the need for giving instructions would be greatly reduced. However, the management areas where maximum potential for improvement exists appear to be cleaning of the hole with compressed air and the refueling of the Pionjär. These two aspects are presented below.

The description of crew efficiency according to the type of equipment provides an interesting observation. The crew efficiency is as follows:

| Time | Air Compressor (%) | Pionjär (%) |
|---|---|---|
| Cutting | 69 | 82 |
| Delay | 31 | 18 |

These data suggest that the advantages in cutting performance enjoyed by the compressor are at least partly offset by improved crew efficiency with the Pionjär. In order to further investigate this finding, the delays inherent with the air compressor were documented.

The two most significant delays associated with the air compressor are (a) cleaning the hole with compressed air and (b) moving to a new hole. Obviously, little can be done by management to reduce the time required to move to a new hole. Cleaning the hole is another matter. Study 1 vividly demonstrates the disadvantages of single-line compressors. The excessive cleaning time noted includes actual cleaning of the hole, disconnecting and reconnecting the hammer, and opening and closing the shutoff valve. This latter operation is usually performed by a second worker, which in itself is not an effective use of personnel. Regardless, the productivity of the crew was greatly reduced because cleaning and cutting could not be done simultaneously. For study 1, the roadway surface was particularly poor and, for this reason, studies 2 and 3 may reflect a typical situation more accurately. Nevertheless, the cleaning times are still significant, approximately 11 percent of the NWTA. This percentage represents a corresponding loss in productivity. It would appear that the department should adopt a policy that all new compressors, whether rented or purchased, should have a minimum of two lines, one of which is reserved for cleaning of the hole. This was the case with study 3, where the hole cleaning did not affect production.

The refueling of the Pionjär is of interest because not only does it contribute to lost production but, more importantly, it is a good indicator of (a) maintenance practices and (b) how well the operator is able to adjust the air-gasoline fuel mixture that affects the energy delivered to the cutting tool. In study 4, the operator refueled a total of six times, as opposed to twice and once for studies 5 and 6, respectively. It was calculated that the Pionjär in study 4 consumed fuel at a rate of 4.16 L/h (1.10 gal/h) as compared with 1.59 L/h (0.42 gal/h) as stated by the manufacturer. In study 5, the calculated rate was 1.55 L/h (0.41 gal/h). Insufficient information was available to determine the rate in study 6.

Additional studies are needed to establish whether or not the situation found in study 4 is an isolated incident. If not, operator training would, of course, be appropriate. Better-trained operators will lead to improved Pionjär efficiency by (a) decreasing the delay time for refueling and (b) decreasing the unit cutting times through increased fuel efficiency.

PRODUCTIVITY GOALS AND PERFORMANCE STANDARDS

Most organizations require a minimum acceptable level of productivity against which actual performance can be measured. For pothole-repair operations, productivity is usually measured in kilograms (tons) of material. One such parameter is the kilograms per day (tons per day) of material placed. Since the cutting rate also establishes the filling and compaction rate of the crew, the amount of material placed must equal the amount of material removed. The information presented previously is sufficient to allow this parameter to be determined. A hypothetical situation is presented below.

| Item | Time (min) |
|---|---|
| Travel to the job site, deploy safety devices, and start cutting operation | 60 |
| Coffee break, add 5 min for restarting operation | 20 |
| Restart operation after lunch | 5 |
| Cleanup and put away tools | 10 |
| Remove safety devices and return to maintenance shed | 60 |

The time remaining is production time, which is NWTA. In this example, NWTA is 295 min.

At this point, recall that the crew efficiency, which is the ratio of cutting time to NWTA, varies by equipment type. If one assumes that cutting will be in progress throughout this 295-min period, then the actual cutting time can be computed as

Cutting time for air compressor = 0.69 x 295 min = 204 min and
Cutting time for Pionjär = 0.82 x 295 min = 242 min.

The most probable cutting rate can be computed by

$$u' = \sum_{i=1}^{n} P_i u_i \qquad (2)$$

where u' is defined as the most probable cutting rate ($min/ft^3$).

By using the information in Table 1, these rates are as follows:

u' for air compressor = 54.9 $min/m^3$ (1.55 $min/ft^3$) and
u' for Pionjär = 81.7 $min/m^3$ (2.31 $min/ft^3$).

Divide the unit rates into the available cutting times to get the daily production:

$V_a$ = 204/54.9 = 3.7 $m^3$/day (130.3 $ft^3$/day) for air compressor and
$V_p$ = 242/81.7 = 3.0 $m^3$/day (104.7 $ft^3$/day) for Pionjär.

If we assume that asphaltic concrete can be compacted to a density of 1920 kg/m³ (120 lb/ft³), then the equivalent daily tonnage of material is

$T_a$ = (3.7)(1920)/1000 = 7.1 Mg/day (7.9 tons/day)
and
$T_p$ = (3.0) (1920)/1000 = 5.8 Mg/day (6.3 tons/day).

Several important points should be made about these rates. First, recall that the Pionjär requires approximately 58 percent more cutting time than does the compressor if probable cutting times are used as the basis for comparison. However, when one considers that there is less delay time associated with the Pionjär (i.e., it has greater flexibility and mobility), then the advantage of the air compressor is reduced to approximately 23 percent. Second, observe that significant improvements in megagrams per day can result by increasing NWTA. For example, a 30-min increase in NWTA will increase the daily production for the compressor to 7.83 Mg/day (8.63 tons/day), a 10 percent gain. On a weekly basis, a 150-min increase corresponds roughly to the difference between working five 7.5-h work days and working three 10-h days and one 7.5-h day. Production could also be substantially increased by using a triple-line compressor with two hammers or by using two Pionjärs. Of course, management must also consider whether or not the crew can fill and compact the holes at this accelerated rate.

## USE OF PERFORMANCE STANDARDS

One of the basic principles of effective management is that one must evaluate past performance. The performance standard is the means by which the maintenance manager can perform this function. Clearly, many variables will influence the productive output of a repair crew. These must be recognized; however, consistent subpar performance should be a signal that crew leadership may be deficient. The causes should be sought out and corrected. The productivity levels suggested in this paper are realistic because they were based on the actual equipment capabilities plus an acceptable percentage of delays. The productivity output can be achieved by the average crew foreperson provided he or she exercises some management skills. It is the responsibility of the state transportation agency to develop those skills.

## CONCLUSIONS

The comprehensive study of the cutting performance of air compressors and gasoline-operated Pionjärs has led to several important conclusions. These are summarized below:

1. The most significant variable that accounts for variability in cutting times is the volume of the hole. Any study of cutting equipment must incorporate this parameter into the analysis before valid comparisons can be made.

2. The comparison of the actual cutting performance of the air compressor and the Pionjär was done on the basis of probable cutting times. Probable times were used to minimize any bias resulting from the skewness of the hole volumes and unit cutting rates. The Pionjär was found to require approximately 58 percent more cutting time than the air compressor for an equivalent size hole.

3. In evaluating management practices, a number of delay times were noted. The crew could make more efficient use of the Pionjär (82 percent) than the air compressor (69 percent). Several suggestions for increasing this efficiency were noted.

4. A procedure for establishing a productivity goal or verifying an existing performance standard was outlined. When the influences of cutting efficiency and management effectiveness are included, the advantage of the air compressor over the Pionjär is reduced considerably. Approximately 23 percent more material could potentially be removed with the air compressor than the Pionjär.

5. Achievement of daily production rates of 7.1 Mg/day (7.9 tons/day) for the air compressor and 5.8 Mg/day (6.3 tons/day) for the Pionjär are clearly realistic because these rates were developed by considering actual field data relative to equipment and management effectiveness. Substantial compliance for most crews should be expected. However, this will occur only through effective leadership by the crew foreperson.

## ACKNOWLEDGMENT

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## REFERENCES

1. J. Douglas. Equipment Costs by Current Methods. Journal of the Construction Division, ASCE, Vol. 104, No. CO2, 1978, pp. 191-205.
2. J. Douglas. Construction Equipment Policy. McGraw Hill, New York, 1975.
3. M. Gates and A. Scarpa. Criteria for the Selection of Construction Equipment. Journal of the Construction Division, ASCE, Vol. 106, No. CO2, 1980, pp. 207-219.
4. Caterpillar Performance Handbook, 9th ed. Caterpillar Tractor Company, Peoria, IL, Oct. 1978.
5. Value Engineering Study of Bituminous Patching. FHWA, Rept. FHWA-TS-78-2, 1978.
6. D. Anderson. A Critical Review of Pothole Repair Technology. Pennsylvania Department of Transportation, Harrisburg, Aug. 1979.
7. SAS User's Guide. SAS Institute, Inc., Raleigh, NC, 1978.

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*Abridgment*

# Portable Hydrodynamic Brine Roadway Deicer System

**MARK A. PICKETT AND JOHN F. CARNEY III**

**The portable roadway deicing system presented in this paper sprays a saturated liquid brine solution under high pressure onto the roadway. Because the sodium chloride is already in solution, it begins to melt the ice as soon as it contacts the roadway. Since the solution has a larger surface area in contact with the ice than the sodium chloride grain, the melting action is quicker and more uniform. The solution is applied at a constant flow rate, and the precise amount of sodium chloride applied per lane-mile of roadway can be determined and controlled. The Connecticut Department of Transportation uses 50-80 percent less sodium chloride per lane-mile with this system as compared with conventional methods. The hydrodynamic system presented here is designed so that it can be removed easily from the truck, which allows the vehicle to be used for other duties.**

In the early 1970s the Connecticut Department of Transportation became aware of the need for an alternative method for deicing the state's roadways. The conventional deicing method consisted of spreading solid sodium chloride on the road by means of a spreader located on top of a dump truck. This system had several drawbacks. Large amounts of solid sodium chloride were being applied--approximately 700 lb/2 lane-miles. In the solid state, sodium chloride has no direct melting action and, if the moisture content of the air is low (below 70 percent), the sodium chloride remains inert. The melting action of sodium chloride only occurs after the solid grains have formed a solution by taking moisture from the air or from the road (1-3). In addition, in the solid state, sodium chloride often cakes up in the spreader. This either disrupts or entirely stops the flow of sodium chloride onto the roadway. Thus, it is difficult to determine or control precisely how much sodium chloride is spread per lane-mile.

These drawbacks prompted the Connecticut Department of Transportation to investigate the possibility of spreading sodium chloride on the roadway as a liquid brine solution rather than as a solid. Because the brine solution is an active deicer, it would eliminate the possibility that the melting process would require a long time to initiate because of insufficient moisture in the air or on the road. The brine solution would also cause a more even melting of the ice. Also, because the brine solution would have a large surface area in contact with the ice, the melting action would occur faster than with the use of solid sodium chloride.

In the liquid state, sodium chloride forms a fully saturated solution when mixed in the ratio of 2.60-2.64 lb sodium chloride/gal water. When this brine solution is sprayed on the roadway, the precise amount of sodium chloride applied per lane-mile can be determined and controlled. Another advantage of spraying a brine solution rather than spreading solid sodium chloride is that the force of the spray striking the ice pack will erode away some of the ice pack.

PROTOTYPE SYSTEM

In the summer of 1976, a brine deicer system was built by the Connecticut Department of Transportation that had a three-way brine-control valve located in the truck cab and nozzles located on a spray bar between the front and rear truck tires (4). The nozzles were positioned at an angle of about 5° (0.10 rad) from the horizontal so that the velocity of the truck as it moved forward could combine with the velocity of the pressurized brine solution (300 lb•f/in²) to cause significant erosion of the ice pack.

In this system, the precise amount of sodium chloride applied per lane-mile was easily controlled. It was found to work effectively when applying only 400 lb of sodium chloride/2 lane-miles. The system included a 1500-gal fiberglass tank; however, because the unit was permanently mounted to the chassis of the truck, it was out of commission when the truck had any mechanical problems, and the truck could not be employed for other maintenance operations in three out of four seasons of the year.

PORTABLE SYSTEM

During 1978-1980, under a contract with the Connecticut Department of Transportation, the civil engineering department of the University of Connecticut designed and constructed six portable systems. The system can be placed in the bed of a dump truck and can be removed from one truck and placed on another truck in about 10 min by one person. This can be done anywhere, even along the side of the road; no special tools are required. Only one temporary and two permanent modifications to the dump truck are necessary. Two quick disconnects are installed--one for the electrical line that allows a switch in the cab to operate the brine three-way control valve and another for the pressure line that operates the pressure gage located in the cab. As a temporary modification, the tailgate is removed.

Four of these portable systems are being employed by the Connecticut Department of Transportation and individual units were delivered to the Utah and the Minnesota Departments of Transportation. The portable deicer system is shown in Figures 1 and 2.

Attachment and Removal of Portable System

The driver attaches the systems as follows:

1. The truck bed is partly raised and the truck is backed under the free-standing system.
2. When the truck is completely under the system, the bed is raised higher, which lifts the front supports off the ground. The telescoping front supports are then retracted and pinned.
3. The bed is completely lowered; this raises the rear support feet off the ground. The telescoping rear supports are then retracted and pinned.
4. The spray bar is then swung underneath the truck and pinned on the right side.
5. The dump system hydraulic line is disconnected and the quick disconnect for the brine system is connected in its place. Now the lever in the cab for raising and lowering the dump body will control the spray bar. The spray bar will lower under its own weight.
6. The electrical quick disconnect for the brine three-way control valve is then connected.
7. The quick disconnect for the cab brine system pressure gage is then connected.
8. The entire system is then fastened to the truck by means of pins and padeyes.

**Figure 1. Portable system in operation.**

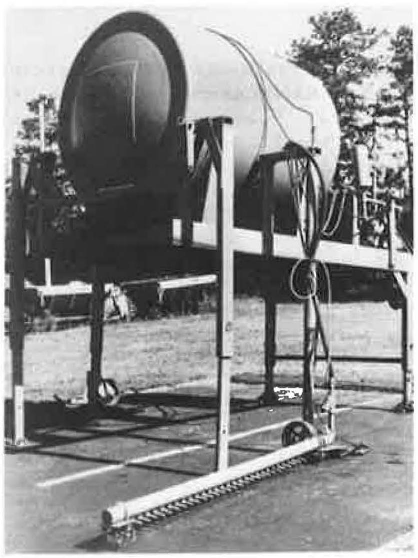

**Figure 2. Free-standing, left-side front view of portable system.**

The procedure for removing the system is similar.

## Brine-Making Facilities

Connecticut is divided into four districts, and each district is equipped with a facility for making and storing brine. The stationary brine-making facilities consist of a 5000-gal brine storage tank and a 375-gal dissolver tank. The dissolver tank is first filled with solid sodium chloride. Then fresh water enters the dissolver tank via a circular diffuser bar located at the bottom of the tank. The fresh water is supplied from the town water system at water-main pressure. As the water rises through the solid sodium chloride in the dissolver tank, the concentration of sodium chloride in solution increases. When the solution level reaches the top of the dissolver tank, the concentration is 100 percent. The solution then enters an effluent pipe via holes in the pipe. The solution then flows by gravity to the storage tank. A sampling valve in the effluent line allows the monitoring of solution concentration. The dissolver tank needs to be filled with solid sodium chloride about every four or five hours. Brine solution is produced at the rate of 10 gal/min.

## Field Experience With the Deicer System

Tables 1 and 2 summarize the results for the winters of 1976-1977 and 1977-1978 (3). No data were taken for the winter of 1978-1979, and the winter of 1979-1980 was too mild in Connecticut to generate meaningful data. All of the data presented in Tables 1 and 2 were obtained from a section of roadway located on I-84 from CT-229 in Southington to CT-70 in Cheshire. Brine solution was applied to the westbound lanes, which included a long continuous grade that rises 320 ft over a distance of 1.8 miles. The entire test section encompassed approximately 15.9 lane-miles, including the lane for truck climbing. Solid sodium chloride was applied to the eastbound (downhill) lanes.

In storm no. 11A of 1977-1978, two applications of brine solution were made on dry, dense, thin pack. After each application, the pack was converted to a light slush. A 96.5 percent saturated solution was used. Ambient temperature at the time of brine application was 22°F.

Storm no. 18 was a lengthy blizzard that occurred on February 6 and 7. On February 8, after approximately 48 h of snowplowing, an extremely tight, dense 0.25-in-thick pack remained on the roadway. This was removed with one brine application. Ambient temperature was 21°F. Maintenance personnel at the test site stated that immediately after application of the brine, either bare pavement resulted or the pack was loosened sufficiently to permit removal by plowing.

On two occasions during storm no. 21 the test section was covered with a thin, extremely slippery

**Table 1. Summary of test results for two winters.**

| Winter | Storm No. | Precipitation Total (in) | Precipitation Type | Roadway Cover | Brine Applied (gal) | Results |
|---|---|---|---|---|---|---|
| 1976-1977 | 10 | 3 | Snow | Mealy snow, thin pack | 2250 | Pavement wet, pack broken |
| | 11 | 1 | Snow | Thin pack | 1350 | Pavement wet with slush |
| | 14 | 8.8 | Snow | Mealy snow | 2250[a] | Pavement wet and clean |
| | 23 | 0 | Snow | Ice | 750[b] | Ice removed on contact |
| 1977-1978 | 11A | 0.4 | Snow | Thin pack | 2250 | Pavement wet with slush |
| | 18 | 18 | Snow | 0.25-in pack | 3700[c] | Pack loosened |
| | 21 | 6 | Snow | Thin pack | 800[d] | Wet |

[a]85 percent brine solution.
[b]65 percent brine solution.
[c]Deicers used only for clean-up operations.
[d]90 percent brine solution.

Table 2. Comparison of crystalline salt used for two winters.

| Winter | Storm No. | Salt Applied as a Solid (ton/lane-mile) | Salt Used to Make Brine (ton/lane-mile) |
|---|---|---|---|
| 1976-1977 | 10 | 0.89 | 0.19 |
| | 11 | 0.73 | 0.11 |
| | 14 | 0.89 | 0.16 |
| | 23 | | 0.12 |
| 1977-1978 | 11A | 0.61 | 0.21 |
| | 18 | 1.19 | 0.35 |
| | 21 | 0.98 | 0.17 |

ice pack. The brine solution completely removed the pack. Ambient temperature was 24°F.

During the winter of 1977-1978, a severe icing condition occurred on a steel open-grid-deck bridge. Maintenance personnel spent two hours in an attempt to remove the ice with conventional methods. But, after one application of a 90 percent saturated brine solution, the bridge was bare of ice, except for a few isolated spots. This remaining ice had been weakened sufficiently to allow removal by traffic.

Field experience has demonstrated that compacted snow and ice covers of 0.25 in or less in thickness are broken up by the pressurized brine solution and are easily removed by plowing. The mechanical action of the brine under pressure is insufficient to loosen the entire snow and ice pack if its thickness exceeds 0.25 in, but the brine solution will penetrate into the pack and will chemically destroy the bond between the pack and the pavement. The mechanical action of passing car tires will then break up the pack.

CONCLUSIONS

The brine roadway deicer system has operated satisfactorily in Connecticut for three winters. The high-pressure spray combined with the brine's deicing characteristics is capable of destroying packed snow and ice. During most storms, sufficient melting action occurred to cause splash up by the traffic within minutes of application of the solution. The portability of the system has proven itself during the limited operations of the winters of 1979-1980 and 1980-1981. The lowest ambient temperature at which the brine solution was used successfully in Connecticut was 20°F, although it is believed that the sodium chloride solution can be used successfully at 15°F.

ACKNOWLEDGMENT

This work was accomplished in cooperation with the Connecticut Department of Transportation and the Federal Highway Administration. The contents of this report reflect our views, and we are responsible for the facts and the accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the state or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

REFERENCES

1. G.E. Scotto. Liquid Treatments of Commercial $CaCl_2$ in Winter Road Maintenance. In Snow Removal and Ice Control Research, HRB, Special Rept. 115, 1970, pp. 156-171.
2. J.O. Kyser. Brine Solution Removes Stubborn Ice. Public Works, Jan. 1971.
3. M.M. Kasinskas. Evaluation of the Use of Salt Brine for Deicing Purposes; Report 3. Connecticut Department of Transportation, Wethersfield, April 1978.
4. M.M. Kasinskas. Evaluation of the Use of Salt Brine for Deicing Purposes. In Snow Removal and Ice Control Research, TRB, Special Rept. 185, 1979, pp. 275-281.

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# Crash Testing of A Portable Energy-Absorbing System for Highway Service Vehicles

JOHN F. CARNEY III

**This paper is concerned with the testing of a new portable energy-absorbing system to be attached to the rear of a highway service vehicle. The research objective was to design a system to provide protection for both the motoring public and the service personnel engaged in maintenance operations on our highways. Its implementation during highway line-striping operations, which are conducted on almost a daily basis, would be of particular value. The energy-absorbing components of the system are four steel pipes connected in a series and cantilevered from the rear of the service vehicle. Full-scale crash tests were conducted to evaluate the performance of the system with respect to (a) structural adequacy, (b) impact severity, and (c) vehicle trajectory. The results of this testing program demonstrate that this energy-absorbing system provides protection during a collision for both the errant motorist and the state personnel working in the service vehicle. The unit is relatively light, inexpensive to construct and repair, and is compactly designed for use on curved and hilly roads.**

In many highway-maintenance operations, personnel and equipment are inadequately protected from collision by an errant vehicle. To provide this needed protection, several portable energy-absorbing systems have been designed. One such unit employs hidro cell components (1,2) attached to the rear of a follower truck in maintenance operations. Another system employs modular crash cushion elements (3), which are 208-2 L (55-gal) drums. This system has been used in the states of Washington and Texas and consists of a trailer that carries 30 crushable barrels (10 rows of 3 barrels).

A modified version of this modular crash cushion has been developed by the highway wayside equipment research office and the equipment office of the Ontario Ministry of Transportation and Communications (4). A third system, which employs crushable Hi-Dri cartridges, has also been designed and manufactured (5).

The hi-dro cell energy-absorbing system and the modular crash cushion system are a study in contrasts. They both dissipate energy on impact, but the portable hi-dro cell unit now being used is approximately 0.91-m (3-ft) long and the modular crash cushion unit is 5.94 m (19.5 ft) in length.

The hi-dro cell system consists of 5 rows of 13 polyvinyl chloride plastic cells enveloped in a corset-like membrane. The entire unit rests on a metal platform that is attached to the rear of the truck. Each cell contains approximately 13.25 L (3.5 gal) of a water-calcium chloride solution. The portable modular crash cushion system is composed of 30 steel drums (10 rows with 3 barrels/row), constructed of 20-gage steel, that rest on a trailer. The trailer is attached at five points to the truck to provide horizontal and vertical stability during impact.

The hi-dro cell unit is portable and relatively easy to install on the rear of a highway truck. Its usefulness as an energy-absorbing system is of primary concern, however, and the present design offers satisfactory protection only for relatively low speeds [less than 48 km/h (30 mph)]. For higher speeds, the present design cannot simultaneously satisfy energy absorption and minimum stopping distance (deceleration) requirements. In addition, the hi-dro cell unit is extremely heavy and has caused failure of the spring system of the truck bed to which the unit is attached.

The modular crash cushion possesses the required energy-absorption capability for speeds of up to 96.5 km/h (60 mph). Furthermore, the 5.94-m length of the barrel system, coupled with the energy-absorbing characteristics of the individual barrels, results in acceptable deceleration levels for impacts of even 96.5 km/h. The modular crash cushion clearly performs its energy-absorbing function admirably. As a practical matter, however, the length of the modular crash cushion inhibits its effective use on winding, hilly roadway networks that exist in many states of the United States.

In addition, day to day use problems have developed with the system. Tires wear much faster than expected when compared with other trailers. This problem is caused by the rigid connection required for stability between the trailer and the towing vehicle. Major difficulties associated with weld fatigue have developed. The Canadian version of the modular crash cushion has experienced similar difficulties. It has been deemed not suitable for permanent rough driving, as in striping operations, and is not recommended for widespread use.

The Hi-Dri energy-absorbing system employs lightweight concrete cylinders bonded to plywood retainer panels and placed inside a plywood box as the energy-absorbing components. The unit functions reasonably well under impact loading. The system is expensive, however, and the condition and position of the concrete cylinders should be checked regularly to ensure proper positioning in the device. This visual inspection is hampered because the energy-absorbing concrete cylinders are enclosed in a fiberglass-crated shell.

An energy-absorbing system composed of sections of steel pipes is described in this paper. The pipes are designed to incorporate the good features of the systems mentioned above, but with several advantages:

1. The pipe system is economical to build and repair,
2. The pipes can be reused after minor impacts by merely jacking them back to their original configuration,
3. The guide system and associated support devices needed in the pipe system are minimal, and
4. The system is compact and designed for use on curved and hilly roads.

## BASIC PROBLEM

The basic problem involves the collision of two bodies: a passenger car traveling at a high rate of speed and a highway service vehicle moving at, say, 16.1 km/h (10 mph). Given the values of the velocity vectors of the car and truck before impact, the appropriate equations of dynamics may be applied to determine the velocities of the two vehicles after the collision and the amount of energy dissipated during impact. In this development, any rotations about the mass centers of the vehicles will be neglected.

The equations of dynamics to be employed include the principle of the conservation of linear momentum and the principle of impulse and momentum. In addition, the definition of the coefficient of restitution and the concept of kinetic energy must be employed. The application of these concepts yields the amount of energy that is to be absorbed, which depends on the following parameters:

1. Weight of the automobile,
2. Weight of the service vehicle,
3. Weight of the energy-absorbing unit,
4. Velocity of the automobile just before impact,
5. Velocity of the service vehicle just before impact, and
6. Angle of impact.

Following recommended guidelines (6), the weight of a heavy automobile was taken as 20 kN (4500 lb). The service vehicle to which the energy-absorbing unit was to be attached weighs 62.3 kN (14 000 lb) and the weight of the energy-absorbing unit was estimated at 8.9 kN (2000 lb). The velocity of the automobile just before impact was set at 88.5 km/h (55 mph) and that of the service vehicle prior to impact was taken as 16.1 km/h (10 mph) in the same direction as the car. The angle of impact was assumed to be zero degrees. For this set of data, the amount of energy to be absorbed by the portable energy-absorbing system can be calculated to be 319 107 J (235 330 ft•lb).

### Energy-Absorption Characteristics of Thick-Walled Rings

Research into the feasibility of employing thick-walled rings as energy-absorbing units when loaded to complete collapse in the plane of the ring has been conducted by Perrone (7). This excellent piece of work involves both experimental and analytical studies that relate the dissipated energy in the ring to its geometry and material characteristics.

Rings that have 0.46-m (1.5-ft) diameters and 12.7-mm (0.5-in) thicknesses made of A53A, A53B, and X52 steel were tested. Uniaxial tensile specimen coupons of these steels exhibited the stress-strain characteristics depicted in Figure 1 (7). Figure 1 shows that the constitutive properties of the three steels are almost identical. Next, load-deformation tests were conducted on the three rings; these results are shown in Figure 2 (7).

### Collapsing Mode

The collapsing mode of the individual pipes is as-

Figure 1. Stress-strain curves for A53A, A53B, and X52 steels.

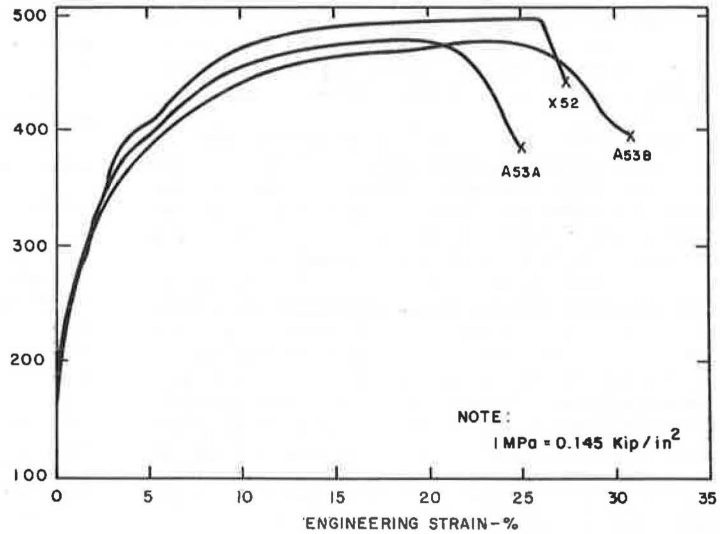
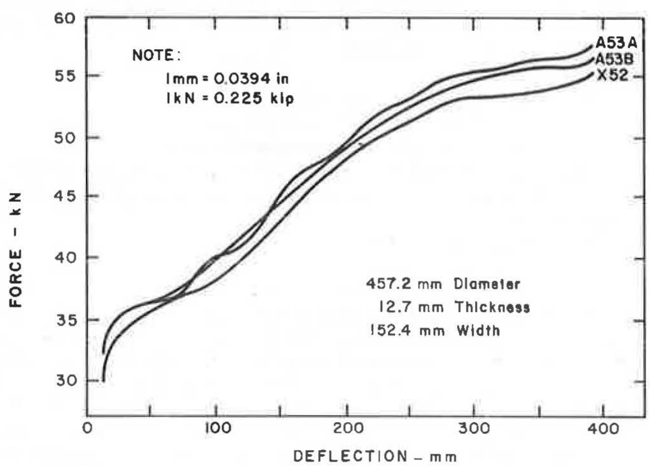



Figure 2. Force-deflection curves for three steel rings.




sociated with the formation of four plastic hinges 90° removed from one another. If we apply the theorem of virtual work and equate the internal and external work done, then

$$2 P_c (R\alpha/2) = 4 M_o \alpha \quad (1)$$

where

$P_c$ = small deflection static collapse load,
$R$ = radius of ring,
$\alpha$ = virtual angle change, and
$M_o$ = yield moment.

It follows that the collapse load is

$$P_c = 4 M_o/R \quad (2)$$

But the yield moment at plastic collapse may be written as

$$M_o = \sigma_o Wt^2/4 \quad (3)$$

where

$\sigma_o$ = static yield stress,
$W$ = depth of ring, and
$t$ = thickness of ring.

which leads to

$$P_c = \sigma_o Wt^2/R \quad (4)$$

Based on the uniaxial data shown in Figure 1, Perrone suggests a value of static yield stress ($\sigma_o$) of 268.9 MPa (39 kips/in²). Note that the collapsing force increases to approximately 2 $P_c$ as the deformation of the ring increases, the energy absorbed in the ring can be closely approximated by the expression

$$\text{Energy} = 1.14 (1.5 P_c)(2 R) = 3.42 \sigma_o Wt^2 \quad (5)$$

Figures 1 and 2 and, therefore, Equation 5 are valid only under static loading conditions. Structural steel is a rate-sensitive material, however, and its properties can change by as much as 100 percent, depending on the strain rates during the deformation process. Much experimental and analytical research has been conducted in this area (8-13). For the range of strains and strain rates to be encountered in this application, Perrone (7) suggests an overall rate sensitivity factor of 1.6. In Equation 6, therefore, if the $\sigma_c$ term is replaced by 1.6 $\sigma_c$, the equivalent dynamic energy absorbed can be written as

$$\text{Dynamic energy absorbed} = 5.47 \sigma_o Wt^2 \quad (6)$$

It has been shown earlier that amount of energy to be absorbed in the heavy automobile collision is 319 107 J (235 330 ft•lb). The energy-absorbing system must absorb this energy in such a controlled way as to satisfy the Federal Highway Administration's (FHWA) guidelines (6), which limit the maximum permissible average vehicle deceleration to 12 g.

It is possible to calculate the minimum required length of the energy-absorbing unit needed to slow a speeding vehicle, as a function of velocity, in order not to exceed 12 g average deceleration. From dynamics, one can write

$$V_c^2 = V_o^2 + 2\alpha s \quad (7)$$

where

$V_c$ = automobile speed before impact,
$V_o$ = automobile speed when automobile and truck move as a unit,
$a$ = average vehicle deceleration, and
$s$ = required length of energy-absorbing unit.

Figure 3. Energy-absorbing pipes.

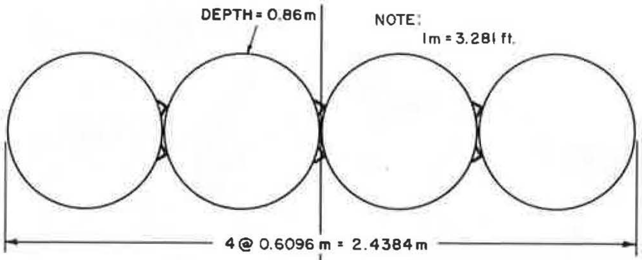
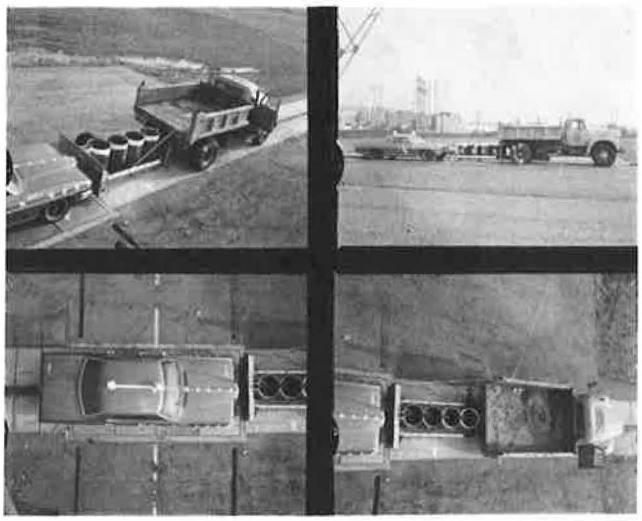



Figure 4. Portable energy-absorbing system.



Suppose the pre-impact velocity of the service vehicle is 16.1 km/h (10 mph). It follows from Equation 7 and the principles of dynamics that, for the case when the automobile impact speed is 88.5 km/h (55 mph), the minimum length of the energy-absorption system is 2.23 m (7.31 ft).

## DESIGN AND FABRICATION OF PORTABLE ENERGY-ABSORBING SYSTEM

The system must absorb 319 107 J (253 330 ft•lb) of energy and possess a collapsing stroke of 2.23 m (7.31 ft). The energy-absorption capacity of one pipe is given by Equation 6. It was decided to employ as the energy-absorbing components, four 2-ft diameter pipes connected in a series, as shown in Figure 3.

Because of vertical stability considerations, the depth of the pipe system was set at 0.86 m (34 in). Then a polymodular design was carried out. In the polymodular design, the wall thicknesses of the two pipes nearest the rear of the service vehicle were taken as 9.525 mm (3/8 in). The third pipe in the series was given a thickness of 6.756 mm (0.266 in). The fourth pipe, the one nearest the impact point, has a thickness of 6.756 mm (0.266 in) and 0.508-m (1.67-ft) long vertical slits 180° apart in its sides. With this setup, the pipe system exhibits increasing stiffness as the collapse length increases. If we assume a 50 percent reduction in energy-absorption capacity in the last pipe due to the existence of the slits, it can be determined from Equation 6 that this system can, when fully collapsed, just absorb the 319 107 J (235 330 ft•lb) of energy to be dissipated.

The system has been designed to possess the following two characteristics:

1. It is capable of absorbing most of the energy dissipated in a high-speed collision between an automobile and the highway service vehicle and
2. It absorbs this energy in such a way that the accelerations and acceleration rates to which the automobile and service vehicle are subjected are within the guidelines specified by FHWA.

The energy-absorbing system involves three components:

1. Service vehicle guidance frame,
2. Energy-absorbing pipes, and
3. Impacting plate assembly.

A photograph of the system mounted on the service vehicle is shown in Figure 4. The impacting plate assembly shown in Figure 4 is constructed of 6061-T6 aluminum. The remaining components of the energy-absorbing system are made of A-36 steel. Note that the steel aluminum guide members in the impacting plate assembly slide inside the steel structural tubing on collapse of the system.

### Full-Scale Crash Testing Program

The crash testing phase of the research was carried out under subcontracts by Calspan Corporation of Buffalo, New York, and the Texas Transportation Institute. Full-scale crash tests were conducted to evaluate the performance of the energy-absorbing system under different impact conditions.

### Test Conditions

The first four tests were carried out by Calspan Corporation.

Test vehicle 1 was a 1971 Ford Maverick that weighed 10.05 kN (2260 lb) and impacted the 62.27-kN (14 000-lb) service truck equipped with the portable energy-absorbing system. The impact velocity was 73.69 km/h (45.8 mph). The impact angle was zero degrees and impact occurred at the centerline of the truck. The average deceleration of the automobile was 9.8 g in this crash test.

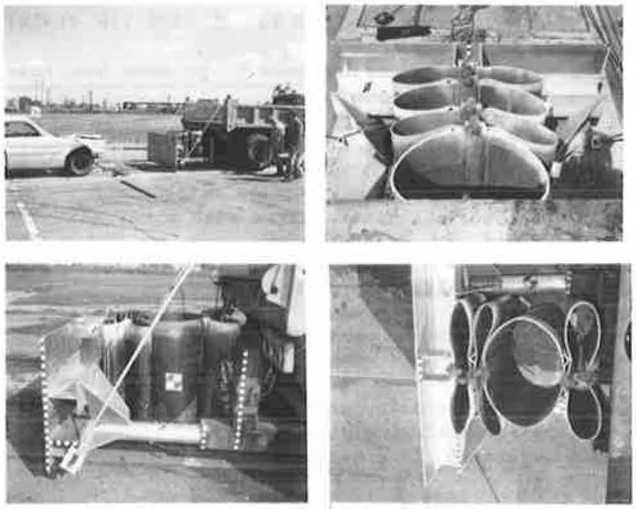
Test vehicle 2 was a 1970 Pontiac that weighed 19.93 kN (4480 lb). The impact velocity was 74.90 km/h (46.55 mph), the impact angle was zero degrees, and impact occurred at the centerline of the truck. In this test, the average deceleration of the automobile was 8.5 g.

Test vehicle 3 was a 1973 Plymouth that weighed 19.93 kn (4480 lb). The impact velocity was 73.18 km/h (45.48 mph). The impact angle was zero degrees, and impact occurred at a 0.762-m (2.5-ft) offset from the centerline of the truck. The average deceleration was 7.7 g.

Test vehicle 4 was a 1973 Plymouth that weighed 19.88 kN (4470 lb). The impact velocity was 73.66 km/h (45.78 mph). The impact angle was 10°, impact occurred at a 0.762-m (2.5-ft) offset from the centerline of the truck, and the average deceleration was 7.8 g.

During the testing program, the four automobiles and the service truck were instrumented with accelerometer packages. These test reports demonstrate the effectiveness of the energy-absorbing system. The four automobiles sustained, in view of their impact velocities, minimal damage, and the

Figure 5. Results of crash test.



service vehicle was undamaged by the four crashes. The same energy-absorbing system was employed for all four tests; the four collapsing pipes were the only system component to be replaced after each crash. Some of the crash test results are shown in Figure 5.

The deceleration levels in the three heavy car crash tests were well within the guidelines set forth (6). In the 10.1-kN (2260-lb) car crash test, however, there was an initial 80 g acceleration "spike" of approximately 10 ms duration, after which the decelerations drop to and remain at acceptable levels. This lightweight vehicle spike was caused by the existence of the 1.9-kN (430-lb) aluminum impacting plate assembly that must be moved to permit the collapse of the energy-absorbing system.

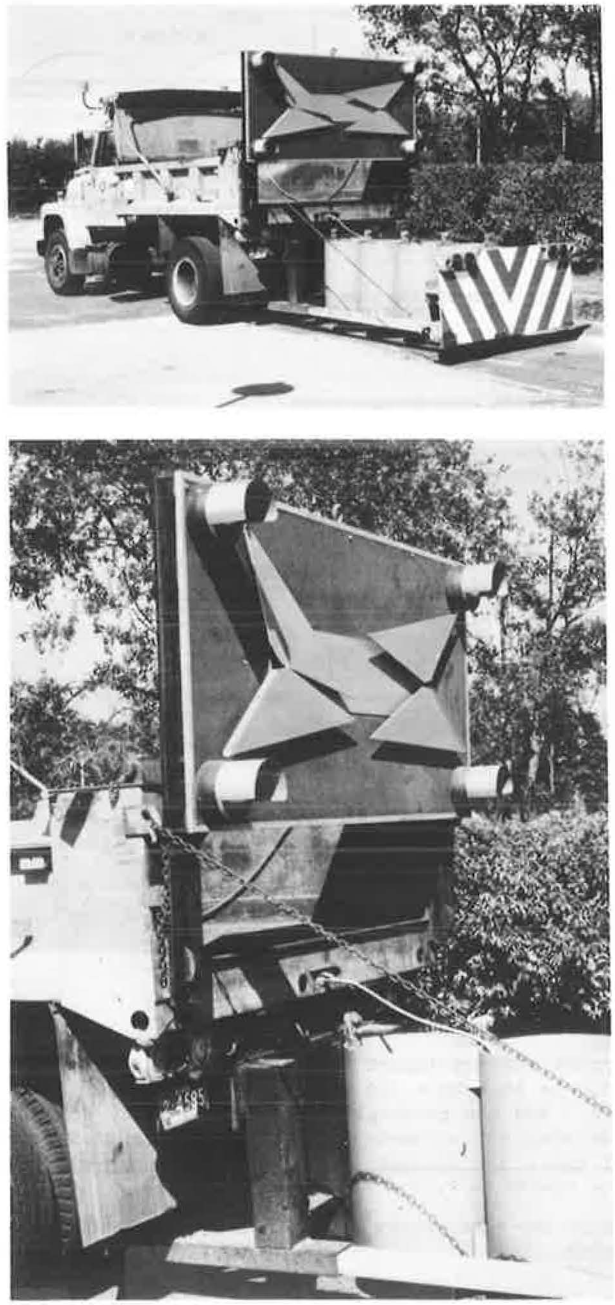
This aluminum assembly was redesigned and its weight reduced to 1.2 kN (278 lb). The light car crash test was then repeated at the Texas Transportation Institute. The acceleration spike did not occur in this test. The current design, therefore, employs the new aluminum impacting plate assembly. Final design details of the system are presented elsewhere (14). Figure 6 shows one of the eight units used by the Connecticut Department of Transportation in its daily maintenance operations.

The performance of the system has been demonstrated. The implementation of this system would provide protection for both the motoring public and the service personnel engaged in maintenance operations on our highways. It would also offer effective protection for the equipment used in these maintenance and repair projects. Of particular value would be its implementation during highway line striping operations, which are conducted on almost a daily basis. In addition, the energy-absorbing system would provide immediate temporary protection during short-term repair or clean up operations (i.e., the repairing of a Fitch sand-filled barrel system).

The energy-absorbing system possesses the following favorable characteristics.

1. It absorbs most of the energy dissipated in a high-speed collision between an automobile and the highway service vehicle, and it absorbs this energy in such a way that the accelerations and acceleration rates to which the automobile and service vehicle are subjected are within the guidelines specified by FHWA.

Figure 6. Connecticut portable energy-absorbing system.



2. It is inexpensive to build; the total assembly can be constructed at an approximate cost of $2000. This figure compares favorably with the cost of existing competitive units.

3. It is inexpensive to repair; under most crash conditions, all that is required is to insert new 2-ft diameter pipes into the system. These pipes are bolted together and cost about $100 each. The aluminum impacting plate and the steel frame under the dump truck body will not usually require repairs. In the case of a collision at low speed, the steel pipes can be jacked back to their original shape and reused.

4. It can be attached to or removed from the service vehicle in minutes.

5. It is compact and designed for use on curved and hilly roads.

6. There is no tendency for the impacting automobile to nosedive under the energy-absorbing unit or catapult over said unit.

7. In the event of an eccentric impact, the intrusion of the impacting automobile into the adjacent traffic lane is minimal.

8. The 62.27-kN (14 000-lb) service vehicle can be expected to suffer no damage during the crash, and adjacent lane intrusion by the truck is not a problem. The same service vehicle was used for all crash tests and suffered no damage.

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This work was accomplished in cooperation with the Connecticut Department of Transportation and FHWA. The contents of this paper reflect my views, and I am 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 state or FHWA. This paper does not constitute a standard, specification, or regulation.

REFERENCES

1. C.Y. Warner and J.C. Free. Water-Plastic Crash Attenuation System: Test Performance and Model Prediction. HRB, Highway Research Record 343, 1971, pp. 83-92.
2. G.G. Hayes, D.L. Ivey, and T.J. Hirsch. Performance of the Hi-Dro Cushion Cell Barrier Vehicle-Impact Attenuator. HRB, Highway Research Record 343, 1971, pp. 93-99.
3. E.L. Marquis, T.J. Hirsch, and J.F. Nixon. Texas Crash-Cushion Trailer to Protect Highway Maintenance Vehicles. HRB, Highway Research Record 460, 1973, pp. 30-39.
4. F.W. Jung. Barrel Trailer for Maximum Collision Protection. Ontario Ministry of Transportation and Communications, Research Rept. 206, Jan. 1977, pp. 1-18.
5. B.O. Young. Crash Test Evaluation of a Hi-Dri Cell Attenuator Mounted on the Rear of a Two Ton Dump Truck. Energy Absorption Systems, Inc., Chicago, IL, 1975.
6. Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances. TRB, Transportation Research Circular 191, Feb. 1978, 27 pp.
7. N. Perrone. Thick-Walled Rings for Energy-Absorbing Bridge Rail Systems. FHWA, Rept. FHWA-RD-73-49, Dec. 1972.
8. J.A. DeRuntz and P.G. Hodge. Crushing of a Tube Between Rigid Plates. Journal of Applied Mechanics. American Society of Mechanical Engineers, Vol. 30, Sept. 1963, pp. 391-395.
9. N. Perrone. On a Simplified Method for Solving Impulsively Loaded Structures of Rate-Sensitive Materials. Journal of Applied Mechanics, American Society of Mechanical Engineers, Vol. 32, Sept. 1965, pp. 489-492.
10. N. Perrone. A Mathematically Tractable Model of Strain-Hardening, Rate-Sensitive Plastic Flow. Journal of Applied Mechanics, American Society of Mechanical Engineers, Vol. 33, March 1966, pp. 210-211.
11. N. Jones. Influence of Strain-Hardening and Strain-Rate Sensitivity on the Permanent Deformation of Impulsively Loaded Rigid-Plastic Beams. International Journal of Mechanical Sciences, Vol. 9, No. 12, 1967, pp. 777-796.
12. N. Perrone. Dynamic Response of Pulse-Loaded Rate-Sensitive Structures. International Journal of Solids and Structures, Vol. 4, 1968, pp. 517-530.
13. N. Perrone. Impulsively Loaded Strain Hardened Rate-Sensitive Rings and Tubes. International Journal of Solids and Structures, Vol. 6, 1970, pp. 1119-1132.
14. J.F. Carney III. Experimental Evaluation of a Portable Energy Absorbing System for Highway Service Vehicles: Final Report for Phase II. FHWA, FHWA-CT-RD-402-F-79-1, 1979, 56 pp.

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*Abridgment*

# Regulation of the Movement of Hazardous Cargoes on Highways

**DAVID M. BALDWIN**

**This paper follows up on the work of an American Association of State Highway and Transportation Officials (AASHTO) task force that looked into the movement of hazardous materials on the highway and what states were doing about it. The current work reviews the AASHTO effort and supplements it with further field contacts. A number of conclusions are reached, and a series of recommendations for state action are offered. Principal conclusions are that the problem is serious but not major when compared with the total traffic safety problem. There are great similarities between safety problems for hazardous material and other traffic safety problems. The existence of many agencies at all official levels as well as in the private sector makes the problem more difficult, and therefore, the need for better communications is obvious. A final conclusion is that all states need adequate legislation, an administrative program, enforcement capability, an educational program, and incident-response capability. Recommendations to the states include the following: (a) adopt appropriate state regulations for motor carrier safety and highway transportation of hazardous materials; (b) identify administrative elements that have responsibilities in the area, define the role of each, and develop effective communications among them; (c) develop an effective incident-response capability; (d) provide training for all personnel; (e) adopt a statewide policy on routing of hazardous materials; (f) institute a data collection system to provide information needed: (g) include hazardous materials considerations in bridge and highway design; (h) conduct a public information program; and (i) consider research in at least three other areas.**

The transportation of hazardous materials on highways presents special problems from the standpoint of safety--not because the chance of an accident is greater but because the results of such an occurrence may be much more severe than in a more usual type of accident and results may occasionally be catastrophic. Although the total number of deaths in accidents that involve hazardous materials is much less than 1 percent of all highway fatalities, the emotional, and therefore the political, impact of such accidents means that the problem demands major attention by responsible public officials.

The magnitude of the problem is difficult to determine with exactitude. The Materials Transportation Bureau of the U.S. Department of Transportation (DOT) states that highway carriers reported more than 12 000 incidents in 1976 and more than 13 000 in 1977 that involved hazardous materials. These totals represent more than 90 percent of incidents reported by all modes; thus, the important part played by highways is emphasized. The highway incidents reported resulted in 16 deaths in 1976 and 30 deaths in 1977 and from 500 to 600 injuries each year (1).

Note that incident and accident are not synonymous. An incident may be a leaking tank observed at a terminal or a barrel that has fallen from a moving truck. This terminology problem has the unfortunate effect of making it difficult to develop reliable figures on events that involve hazardous materials.

A study in Virginia suggests the extent of highway movement of hazardous materials. Based on surveys at 38 locations throughout the state, it was estimated that approximately 13 percent of all trucks were carrying some hazardous materials and that 10 percent were carrying quantities sufficient to require the use of placards under federal regulations. Nearly 65 percent of the hazardous materials transported were flammable or combustible liquids (2).

The growth of the problem in the transportation of hazardous materials and its increasingly catastrophic effects prompted the American Association of State Highway and Transportation Officials (AASHTO) in 1978 to appoint a task force on hazardous materials. This group was charged with investigating criteria for the movement of hazardous materials, determining what states were doing in regard to regulating such movements, and finding out what regulations and criteria for the control of such movements were in effect. For this purpose a questionnaire was sent to all states, and responses were eventually obtained from all but four.

Following tabulation of the questionnaire returns, a small project was undertaken under the National Cooperative Highway Research Program (NCHRP) to study information collected by the questionnaire survey and to prepare a report that analyzes the information, suggests appropriate actions that individual states could take based on the analysis, and recommends specific research needs to further resolve the concerns about highway transport of hazardous materials (3).

## SURVEY RESULTS

As a result of the review of the questionnaire returns and other information gathered from contacts with officials and others, a number of conclusions have been drawn.

### Safety of Transport of Hazardous Materials

The problem of safe transportation of hazardous materials is a very large one but, in relation to the total problem of transportation safety, it is not major. The total number of highway deaths from the transport of hazardous materials has been in the range of 20-30 a year, or less than 0.1 percent of the total traffic death toll. Unfortunately, the relationship must be stated in relatively imprecise terms because more exact figures are not available--and that is part of the problem.

The potential for a hazardous materials transportation accident on the highway is roughly in proportion to the volume of truck traffic, with from 10 to 15 percent of trucks on the average carrying some form of hazardous material. Accident probability is related to exposure, and the case of hazardous materials is no exception.

### Accident Prevention

Accident prevention efforts for hazardous materials transportation are no different from such efforts for general transportation. The prevention of an accident for a truck carrying a cargo of hazardous materials is basically no different because of the cargo. The difference is evident after an accident occurs, when the cargo may make the consequences of the accident more severe. It is also true that, because of the potentially more-severe consequences, it may be desirable to accentuate and expand the usual prevention techniques in an effort to reduce the likelihood of an accident. There is also a need for new and different activities related to response techniques, clean-up procedures, and similar matters.

### Number of Agencies Involved

The great number of agencies involved in the management of hazardous materials transportation creates a major problem of coordination. At the federal level, at least the following agencies have a share of the responsibility and authority for the safe transport of hazardous materials on the highways:

1. DOT,
2. Materials Transportation Bureau,
3. Bureau of Motor Carrier Safety,
4. Environmental Protection Agency,
5. Nuclear Regulatory Agency,
6. Federal Emergency Management Agency, and
7. National Transportation Safety Board.

At the state level, the list is even longer, with as many as 10 agencies having some degree of involvement in some states. Other agencies enter the picture at the local level. To this confusing mass of official agencies must be added nonofficial groups that represent manufacturers, shippers, carriers, and users. Either as individual commercial enterprises or through a trade association, these groups have a legitimate concern as well as a responsibility to the public for safety of transportation.

There is a substantial need for better communications at all levels. The great number of agencies involved suggests immediately the need for communications. That the need exists was evident by a comparison of the questionnaire returns with responses to similar questions posed by the Bureau of Motor Carrier Safety of DOT. Discrepancies in the two sets of responses clearly indicate confusion and gaps of knowledge in some areas. When one responder answers that there are no regulations in a particular area and another cites chapter and section, the problem is quite apparent.

The need is for better communications among federal, state, and local agencies, as well as from the official agencies to shippers and carriers. In addition, the general public needs to be informed of the hazards as well as the safety of hazardous materials transportation.

### State Safety Program

A complete package at the state level includes, at a minimum, adequate legislation, an administrative program, enforcement capability, an educational program, and incident-response capability. A complete program means one designed to prevent the occurrence of accidents as well as to minimize the effects of an accident should one occur. Thus, adequate legislation includes rules for safe packaging and marking of hazardous cargoes as well as rules for safe driving of the vehicles, including requirements for both drivers and vehicles.

With a sound legislative base, a good administrative program can be developed. Rules must be enforced, otherwise they become empty threats ignored by all except the conscientious. Education becomes a necessary adjunct to enforcement. Finally, because accidents will occur, the ability to respond quickly and properly to an emergency is essential. Here the multiplicity of agencies can cause problems because there must be a clear assignment of responsibility and authority at the scene. Unless this is spelled out in advance, confusions, contradictions, and uncertainties will be likely to occur.

Any comprehensive program will cost money. Funding needs and possible sources of funds for one state are suggested in a study prepared by the California Highway Patrol in response to a legislative request (4).

Recognize that, in the larger sense, the problem is one shared by the states and the federal government, and the latter has important responsibilities that are not detailed here.

## RECOMMENDATIONS

The following recommendations are directed toward state departments of transportation and highways, in view of the AASHTO background for the project. Some of the recommendations of necessity extend beyond the jurisdiction of these departments, and must be so considered. Not all of the recommendations will apply in every state because the states are in different stages of development in the matter of hazardous materials transportation. Each state will have to examine the recommendations against its existing program and decide whether further action is appropriate.

The recommendations are as follows.

### Adopt Appropriate State Regulations

Adopt appropriate state regulations for motor carrier safety and for highway transportation of hazardous materials. In 20 percent of the states there are currently no state regulations that apply directly to the transportation of hazardous materials. In many others, regulations are not complete. Some existing regulations apply only to for-hire carriers or to vehicles in intrastate commerce. Exemptions are frequently granted to haulers of agricultural products, with the result that many vehicles that carry dangerous materials are not subject to any state regulation.

Title 49 of the Code of Federal Regulations contains very complete rules, not only for the safety of all motor carriers but also for hazardous materials transportation. Every state should examine its own rules to be sure that the applicable sections of Title 49 are in effect. State adoption of the appropriate sections will not only make it possible to enforce the rules in state courts, but the rules can also be made to apply to all vehicles and to all classes of carriers. By following the federal rules, consistency among the states will be achieved and shippers, carriers, and users will all benefit.

Questions have been raised about preemption by the federal rules. This subject has been thoroughly explored by Lawrence W. Bierlein for the Illinois Department of Transportation, and preemption does not appear to be a bar to state action (5).

The recommended regulations establish rules for highway transportation of hazardous materials as well as basic rules for drivers and vehicles used for transporting all types of cargoes. As noted earlier, a hazardous cargo in traffic is subject to the same chance of accident as any other cargo, and it behooves the responsible authorities to provide the best possible drivers and vehicles for dangerous cargoes in view of the potential for severe consequences of an accident.

### Identify Areas of Responsibility Within States

Identify administrative elements in the state that have responsibilities in the area, define the role of each, and develop effective communications among them. In nearly all states, several agencies share the responsibility for the safe transport of hazardous materials. In few cases is there a clear-cut line of authority, with one agency identified as the lead agency. This is to some extent a reflection of the situation at the federal level and may not be fully resolved at the state level until it is at the federal level. Complicating the matter is the frequent breakdown in communications, even within the state, to say nothing of such failures between state and federal or between state and local agencies.

The three elements of this recommendation--identification, role definition, and communications--are so intertwined as to make them nearly inseparable. There is a pressing need to identify the many groups at both the state and local levels, and then to clearly and publicly determine the role of each. A means of communication must then be established so that each agency will know what the others are doing. Only in this fashion can order be brought out of the chaos that now exists in most states.

### Develop Incident-Response Capability

Develop an incident-response capability that will minimize the effects of a hazardous materials accident. The ability to respond quickly, effectively, and safely to a hazardous materials incident or accident is a first order of business for any state. If such an event occurs, the burden of rapid and knowledgeable response falls on some public authority. Failure to act correctly in such an instance can exacerbate a situation, cause additional and unnecessary casualties, and bring about a public reaction that may be out of proportion to the results.

An adequate response effort requires trained personnel, available on a round-the-clock basis, who have proper equipment, and are alerted by a good communications system. Many horror stories can be told of incidents that involved untrained response personnel, some of whom lost their own lives as a result of lack of knowledge.

### Provide Training for Administrative, Enforcement, and Response Personnel

The subject of hazardous materials is large, complicated, and generally strange to anyone who has not been closely involved in the matter. All those at the state level who have any part in the problem need to have special knowledge. This applies to administrative personnel, enforcement officers, and response personnel.

## Adopt a Statewide Policy on Routing of Hazardous Materials

Many local communities have established routing requirements for hazardous materials cargoes. Blanket prohibitions, sometimes imposed, create serious questions of restraints on commerce and necessary exemptions for local deliveries may make the restrictions ineffective.

The Federal Highway Administration has sponsored a research project to develop criteria for selecting routes for transportation of hazardous materials (6). Findings of this study should give guidance to the states in the formulation of reasonable policies. For the benefit of carriers as well as public safety, such policies should be as consistent as is legally and politically feasible within all incorporated areas of the state.

## Data Collection

Institute a method of data collection that will provide information on the frequency and causal factors of hazardous materials incidents and accidents. Currently, information in most states is not sufficient to determine, with any degree of accuracy, how many hazardous materials accidents occur, to say nothing of being able to determine causes or even contributing circumstances. It should not be too difficult to institute a proper collection system, either through the regular state accident-reporting mechanism or through the motor carrier accident-reporting system. Without such information, however, authorities have no accurate measure of the magnitude of the problem and no sound guidance as to appropriate remedial measures.

## Include Hazardous Materials Considerations in Highway and Bridge Planning and Design

Hazardous materials spills have obvious potential impacts on groundwater supplies, wildlife, and vegetation. These threats to drinking water sources and to aquatic ecosystems may be lessened if attention is given to the problem during the planning and design phases of highway and bridge projects.

## Conduct a Public Information Program

Conduct a public information program to explain transportation of hazardous materials to the general public. The public is poorly informed about transportation of hazardous materials, and a public information program is needed to explain the situation--not only to allay unnecessary fears but also to alert people to the actual dangers that can exist if an accident happens. Although not all perceived dangers are real, the public does not always recognize actual dangers when they are present, and unnecessary casualties have resulted. A good public information program could save lives.

## Further Research

Consider further research in at least three areas. Determine the best pattern for administrative organization at the state level and how this can be fit into existing state organizational structures, which differ widely. A study of current organizational patterns and relative advantages and disadvantages could lead to recommendations for the most-effective way to generate an effective hazardous materials program.

Develop a training program geared to state needs in administration, enforcement, and emergency response. Couple this with the devising of a practical method of making this available to state and local personnel.

Undertake a comprehensive study of risk analysis methodology and its application to current problems, including route and mode selection. The need for a state-of-the-art study of risk analysis methodology has been identified as a major issue, and this proposal merely goes one step further in suggesting that there could be immediate use in route selection and in comparing hazards by mode. It has been suggested that increased enforcement in the highway field might shift some cargoes to the railroads. At present there is probably not sufficient information to know whether this would be beneficial or harmful from the overall safety standpoint.

## ACKNOWLEDGMENT

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## REFERENCES

1. U.S. Department of Transportation. Eighth Annual Report on Hazardous Materials Transportation. U.S. Government Printing Office, 1977, 74 pp.
2. J.W. Schmidt and D.L. Price. Virginia Highway Hazardous Materials Flow: 1977 Survey. Virginia Polytechnic Institute and State University, Blacksburg, 1977, 37 pp.
3. D.V. Baldwin. Regulation of the Movement of Hazardous Cargoes. National Cooperative Highway Research Program, rept. forthcoming.
4. Department of the California Highway Patrol. Hazardous Substances Highway Spills Study. California Legislature, Response to Senate Resolution 52 and House Resolution 62, 1978-1979.
5. L.W. Bierlein. Transportation of Hazardous Materials in Illinois: An Appraisal of the Need for and Lawfulness of Regulatory Control by the State of Illinois. Lipman Public Policy Studies, Washington, DC, 1977.
6. Peat, Marwick, Mitchell and Company; Institute for Safety Analysis. Technical and Staffing Proposal for the Development of Criteria to Designate Routes for Transporting Hazardous Materials. Federal Highway Administration, 1979, 71 pp.

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