EVALUATION AND SUMMARY OF STUDIES IN SPEED CONTROL METHODS IN WORK ZONES

By

Rahim F. Benekohal
Lynn M. Kastel
Mohamed I. Suhale

A Report of the findings of:
Investigation of speed control methods in work zones

Project IHR-014
ILLINOIS COOPERATIVE HIGHWAY RESEARCH PROGRAM

Conducted by the
DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

For the
ILLINOIS DEPARTMENT OF TRANSPORTATION
In Cooperation with the
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

FEBRUARY 1992
**Title and Subtitle**
Evaluation and Summary of Studies in Speed Control Methods in Work Zones

**Authors**
R. F. Benekohal, L. M. Kastel, M. I. Suhale

**Performing Organization**
Department of Civil Engineering
University of Illinois at Urbana-Champaign
205 N Mathews Ave
Urbana, IL 61801

**Sponsoring Agency**
Illinois Department of Transportation
Bureau of Materials & Physical Research
126 East Ash St.
Springfield, IL 62704

**Abstract**
This report summarizes and evaluates the important findings from the literature review of the studies on work zone speed control techniques. The following treatments are included in this report: 1) flagging, 2) lane width reduction, 3) law enforcement, 4) changeable message signs (CMS), 5) rumble strips, and 6) flashing beacons. The effects of the speed control treatments on speed and traffic flow are evaluated based on: A) experiences with treatment, B) effects of treatment on speed, C) effectiveness of treatment, and D) comments about treatment. A brief description of the conditions under which the treatments were applied is provided, and the speed reduction effects of each technique are discussed. A reference matrix was prepared to identify publications related to each type of speed reduction treatment used in work zones.

**Key Words**
Work Zone, Traffic Control, Flagging, Lane Width, Law Enforcement, Changeable Message Signs

**Distribution Statement**
Unclassified

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized
ACKNOWLEDGEMENT AND DISCLAIMER

This research report is based on the results of Project IHR-014 - Investigation of Speed Control Methods in Work Zones. This study is sponsored by the Illinois Department of Transportation and the U. S. Department of Transportation, Federal Highway Administration. The authors would like to thank the Project Advisory Committee members for their comments and suggestions and C. Wienrank for review of the report.

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.
TABLE OF CONTENTS

ABSTRACT .......................................................... ii

1. INTRODUCTION .................................................. 1

2. FLAGGING ....................................................... 3
   2. A. EXPERIENCES WITH FLAGGING .......................... 3
      2. A. 1. FLAGGING ON MULTI-LANE HIGHWAYS .......... 3
      2. A. 2. FLAGGING ON ONE-WAY OPERATIONS .......... 3
   2. B. EFFECTS OF FLAGGING ON SPEED ..................... 4
   2. C. EFFECTIVENESS OF FLAGGING .......................... 5

2. D. COMMENTS ABOUT FLAGGING ................................ 5

3. LANE WIDTH REDUCTION ....................................... 6
   3. A. EXPERIENCES WITH LANE WIDTH REDUCTION .......... 6
   3. B. EFFECTS OF LANE WIDTH ON SPEED .................... 7
   3. C. EFFECTIVENESS OF LANE WIDTH REDUCTION .......... 7

4. LAW ENFORCEMENT ............................................. 8
   4. A. EXPERIENCES WITH LAW ENFORCEMENT ................. 8
   4. B. EFFECTS OF LAW ENFORCEMENT ON SPEED ............. 9
   4. C. EFFECTIVENESS OF LAW ENFORCEMENT ................. 10
   4. D. COMMENTS ABOUT LAW ENFORCEMENT ................... 10

5. CHANGEABLE MESSAGE SIGN (CMS) ............................ 11
   5. A. EXPERIENCES WITH CMS ................................ 11
   5. B. EFFECTS OF CMS ON SPEED ............................. 11
   5. C. EFFECTIVENESS OF CMS ................................. 12
   5. D. COMMENTS ABOUT CMS ................................... 12

6. RUMBLE STRIPS ................................................ 12
   6. A. EXPERIENCES WITH RUMBLE STRIPS ..................... 12
   6. B. EFFECTS OF RUMBLE STRIPS ON TRAFFIC ............... 13
   6. C. EFFECTIVENESS OF RUMBLE STRIPS .................... 13
   6. D. COMMENTS ABOUT RUMBLE STRIPS ....................... 13

7. FLASHING BEACONS ............................................ 14
   7. A. EXPERIENCES WITH FLASHING BEACONS ................. 14
   7. B. EFFECT OF FLASHING BEACONS ON SPEED ............... 14
   7. C. EFFECTIVENESS OF FLASHING BEACON .................. 15
   7. D. COMMENTS ABOUT FLASHING BEACONS ................... 15

8. CONCLUSIONS ................................................ 16

REFERENCES .................................................. 17

APPENDIX A .................................................. 20

APPENDIX B .................................................. 24
1. INTRODUCTION

As a part of a study on speed control methods in work zones, an extensive literature survey of publications related to speed control in work zones was conducted to identify previous studies and to utilize their findings in planning future research activities. A reference matrix was prepared to identify the studies pertaining to particular speed reduction methods. The reference matrix contains eight subjects, six of which are directly related to work zone traffic control. The other two subjects are accident analysis and traffic management, which address issues indirectly related to speeding in the work zone. The last column of the matrix provides information about the contents of the publications. The reference matrix is given in Appendix A.

This report contains important findings from previous studies on work zone speed control techniques. It does not include the findings from ongoing research projects at the University of Illinois. Reports and publications on the effects of several work zone speed control devices are reviewed. Summaries of these studies are included in Appendix B. The effects of speed control treatments on speed and traffic flow are evaluated. The evaluation is based on the findings of previous literature and experiences with each speed control method. The evaluation and results of the speed reduction techniques are discussed in the following categories:

(1) experiences with treatment,

(2) effects of treatment on speed,

(3) effectiveness of treatment,
(4) comments about treatment.

The experiences with the treatment category contains a brief description of the conditions in which a treatment was applied. The ability of a treatment to reduce speed of vehicles was considered in evaluating the effects of the treatment on speed. The effectiveness of a treatment is evaluated in terms of performance continuity and its impact on speed reduction. In the comments category, factors such as the effect of the treatment on traffic flow or safety and other factors relevant to the treatment are included.

In this report the following speed reduction treatments are included:

1. Flagging.
2. Lane width reduction.
3. Law enforcement.
5. Rumble strips.
6. Flashing beacons.

For the advantages and disadvantages of the first four treatments, one may refer to reference 30. Rumble strips and flashing beacons had limited applications in work zones, and were used mostly in urban areas or under low speed conditions. Therefore, the results of the experiences may not be applicable to high-speed traffic conditions.
2. FLAGGING

2. A. EXPERIENCES WITH FLAGGING

Flagging is used for traffic control and speed reduction in various types of work zones. Proper flagging procedure as given in the Manual on Uniform Traffic Control Devices (MUTCD) must be followed.

2. A. 1. FLAGGING ON MULTI-LANE HIGHWAYS

Richards et al. (31, 32) evaluated the immediate (1-2 hours) effects of MUTCD flagging (flagging according to MUTCD procedures) and innovative flagging (MUTCD flagging plus pointing to the speed limit sign) on vehicle speed, and suggested maximum speed reduction values for different highway work zones. Noel et al. (24, 25) evaluated the long-term (two weeks) and the short-term (within three days) effects of MUTCD flagging and innovative flagging on speed reduction on multi-lane freeways.

2. A. 2. FLAGGING ON ONE-WAY OPERATIONS

Ullman et al. (36) suggested alternatives to the use of flaggers to control an alternating one-way traffic operation. Bookers et al. (1) evaluated the effectiveness of using a reusable temporary stop bar (stop line) and a free standing oversized stop/slow sign paddle where flaggers were employed to control one-way traffic operation. Ullman et al. (35) studied the effects of installing portable traffic signals in place of flaggers where traffic operations were one-way. Burritt et al. (2) used a pilot
car operation in a construction zone with an alternating one-way traffic operation.

2. B. EFFECTS OF FLAGGING ON SPEED

The MUTCD and innovative flagging were effective in reducing the speed of vehicles. Some immediate effects (1-2 hours) of the innovative and MUTCD flagging were speed reductions in the range of 4-16 mph and 3-12 mph, respectively (31,32). The innovative flagging caused an additional 3 mph speed reduction than the amount needed in one site, but on four sites it did not lower the speed to the needed level. The MUTCD flagging did not lower the speed to the needed level at any of the six sites.

The innovative and MUTCD flagging did not consistently lower the speed when short-term (within 3 days) and long-term (10-15 days) effects of the treatment were studied. The MUTCD flagging caused a speed change, for cars and trucks combined, ranging from +4.4 mph (an increase) to -4.7 mph (a decrease), while the range for innovative flagging was from +1.4 mph to -6.7 mph (24, 25). The innovative flagging reduced the speed by 2-4 mph more than the MUTCD flagging (31). The flagging produced greater speed reductions at two-lane two-way rural highways and urban arterials than at urban and rural freeways.

Flagging was effective in long-term (two weeks) and short-term (few days) speed reduction treatments where only one lane out of three lanes of freeway was open to traffic (24, 25). Flagging was less effective when two out of three lanes of the freeway were open (24, 25). The effectiveness of flagging treatments appeared to
depend on the number of lanes that remained open to traffic in work areas.

Flaggers were effectively used to control one-way traffic operations at a work zone lane closure on a two-lane two-way highway (1).

2. C. EFFECTIVENESS OF FLAGGING

Flagging is an effective speed reduction treatment, in most cases, when it is performed properly. When placed in a construction zone, a flagger is expected to continuously direct the traffic. Motorists rely on the messages flaggers provide, even if they do not follow the flaggers' messages (e.g. reduce their speed). The effectiveness of flagging may decrease over time due to fatigue or boredom of the flagger (30). Such a flagger not only will be less effective, but will also be perceived by drivers as a less reliable source of information. Flagging may become a less effective method of speed control in adverse weather and low visibility conditions.

2. D. COMMENTS ABOUT FLAGGING

Flaggers may be able to detect out of control vehicles and may use this information to seek a safer place, and may be able to alert the construction crew when an out of control or excessively speeding vehicle is approaching them. Safety considerations must be taken into account when a flagger is placed in a construction zone. Flaggers carry a serious responsibility in protecting the construction crew and directing traffic. Therefore, they must
always pay attention to the motorists and construction activities. When a flagger is used, there is no guarantee that they will perform their duties properly all of the time. Because flaggers can easily become fatigued or bored they need to be relieved every few hours. Mechanical devices (e.g. robotics arms) should be considered instead of flaggers in construction zones with a higher risk of accidents.

3. LANE WIDTH REDUCTION

3. A. EXPERIENCES WITH LANE WIDTH REDUCTION

Dudek et al. (3) reported that reducing the lane width to 10-11 ft (on Katy Freeway reconstruction project) did not change the overall operating speed before and during construction conditions. Only one out of five segments of the freeway showed any significant speed reduction during construction. Graham et al. (9, 11) evaluated the effects of funneling and reducing widths of the traveled way at the approach to the construction zones, where the right lane of a four-lane undivided urban arterial was closed.

Richards et al. (31,32) evaluated speed reduction effects of reducing lane widths to 11.5 ft. and to 12.5 ft. On two-lane highways, cones were used to funnel traffic through a 12.5 ft. path. On multi-lane highways a 12.5 or 11.5 ft. lane between lane lines and cones was provided by positioning the cones along the pavement edges.
3. B. EFFECTS OF LANE WIDTH ON SPEED

Based on previous studies, lane width reduction does not have consistent beneficial effects on speed. Lane width reduction did not exhibit any significant decrease in traffic speed (3, 9). However, studies stated that while lane width reductions had very little or no effect in urban and rural freeways, vehicles did slow down as much as 8 mph on rural two-lane two-way highways (31, 32). The lane width reduction treatments resulted in a 0-7 mph decrease in speed (31,32).

3. C. EFFECTIVENESS OF LANE WIDTH REDUCTION

The effectiveness of lane width reduction treatments seems to depend upon the method of reducing the lane width and the length of the narrow section. If lane width reduction is achieved by installing concrete barriers, then the barriers are unlikely to be moved and the treatment would be reliable in achieving the lane width reduction. However, if reduction is achieved by means of tapering with cones or barrels, then it is unlikely that the lane width reduction treatment will be reliable without some periodic realignment or replacement of the devices.

3. D. COMMENTS ABOUT LANE WIDTH REDUCTION

Safety effects of the lane width reduction treatment are yet to be determined. One study (3), in which concrete barriers were placed at least one foot from the edge of an 11 foot narrow lane, reported that fatality and injury rates in the construction zone were lower than fatality and injury rates for all accidents in that
state. However, in another study (11) it was reported that the project with reduced lane width experienced a 17.6% increase in accident rates during the construction, while projects with normal width had only a 6.6% increase in accident rates.

A narrower lane may not provide enough room for lateral movement or for driver errors. In narrower lanes, drivers may increase their space headways to compensate for the lack of lateral clearance. This action would reduce the capacity of work zones and may cause an interruption in traffic flow (acceleration and deceleration) which may increase the chance of an accident.

4. LAW ENFORCEMENT

4. A. EXPERIENCES WITH LAW ENFORCEMENT

Graham et al. (11) reported on the effects of law enforcement on speed and erratic maneuvers on a two-lane (per direction) rural freeway reduced to a two-lane two-way operation by means of a crossover section (erratic maneuvers were defined as a single vehicle suddenly swerving or braking on approaching a transition area). Noel et al. (24, 25) evaluated the long term (two weeks) and short term (within three days) effectiveness of law enforcement on speed reduction on a six-lane freeway construction zone. The treatments were a marked police car with cruiser lights and radar on, and a uniformed police officer controlling traffic.

Richards et al. (31, 32) investigated the immediate effects (1-2 hours) of the following law enforcement treatments on speed
reduction: stationary patrol car, police traffic controller, circulating patrol car, stationary patrol car with lights on, and stationary patrol car with radar on.

4. B. EFFECTS OF LAW ENFORCEMENT ON SPEED

The effects of the police presence on traffic speed varies with the function assigned to the law enforcement officer. The law enforcement by a highway patrol man car stationed on the road side not only reduced the erratic maneuver rate, but also reduced the mean vehicle speed by 2.77 mph (11). The immediate effects (1-2 hours) of law enforcement treatments on speed were a reduction of 2-3 mph for a circulating patrol car, 9-13 mph for a police traffic controller, and 3-12 mph for a stationary police car (31,32). Thus, the most effective law enforcement treatment was a uniformed police officer standing on the roadside and controlling traffic and the least effective treatment was the circulating patrol car. The immediate speed reduction effects of the stationary police car treatment was consistently less than the innovative flagging treatment.

The long-term and short-term effects of the police traffic controller treatment on multi-lane freeways were speed reductions in the range of 2.3-6.8 mph using data for all vehicles (24, 25). The results from the police radar treatment were not as consistent as those from the police traffic controller, with speed reductions ranging from +3.6 mph to -8.4 mph. Police radar and police controllers were found to be effective in both long-term and short-term experiments. Police controllers reduced speeds by 6.3 mph
over a short-term period and by 6.8 mph over a long-term period when one out of three lanes was open to traffic (24, 25). Police radar treatments were effective in reducing speeds by 5.4 mph during a long-term period when one lane was open to traffic (24, 25).

4. C. EFFECTIVENESS OF LAW ENFORCEMENT

A police officer stationed at one point would increase the speed limit compliance significantly at that location. The effect would be limited to a smaller area, however. On the other hand, a circulating police car would impact a larger area, but it would have less overall speed reduction effects. Some drivers with citizen band radios communicate police presence in the work zone area and select their speed accordingly. Such communication reduces the risk of getting a speeding ticket.

4. D. COMMENTS ABOUT LAW ENFORCEMENT

Police are effective in reducing speed when they actively enforce the speed limit laws in a work zone. However, it becomes very expensive to have law enforcement officers in every work zone. A uniformed police officer directing traffic must always be alert and therefore must be relieved every few hours, resulting in a need for additional trained officers. Law enforcement officers may not be readily available or willing to direct work zone traffic.
5. CHANGEABLE MESSAGE SIGN (CMS)

5. A. EXPERIENCES WITH CMS

Dudek et al. (5) studied effects of using CMSs for freeway maintenance operations. The CMS was used effectively to direct traffic, or to encourage traffic to leave the closed lane. Dudek et al. (6) evaluated configurations with a reduced number of traffic control devices. Hanscom et al. (12) reported on the effects of CMSs on highway lane closures. It was found that when a CMS was used more drivers changed to the through lane before they approached the work zone.

Pigman et al. (27) evaluated the effectiveness of supplemental lane closure warning signs and variable message signs placed before the taper. The results indicated that 21.9% of the vehicles were in the closed lane, at a location 0.1 miles before the taper, when standard traffic control devices (TCD) were in place. This value was reduced to about 10.9% when a CMS and supplemental signs were added.

Richards et al. (31, 32) evaluated short-term (few hours) effects of a CMS on slowing down traffic at six work sites in Texas. The CMS displayed speed messages or speed and information messages.

5. B. EFFECTS OF CMS ON SPEED

Changeable message signs are used effectively to encourage and direct traffic to leave closed lanes (5, 6, 27) and to provide better lane distributions (12). A specific diversion message is
more effective than a general diversion message (5). It was reported (12) that there was a speed reduction of 7.0 to 7.6 mph at the taper when a CMS was used, compared to when no CMS was used at the work zone. Although changeable message signs are beneficial in improving traffic flow, they are not very effective in reducing traffic speed. The immediate effects of utilizing a CMS was a decrease in speed of 0-5 mph (31, 32).

5. C. EFFECTIVENESS OF CMS

A CMS gets the attention of drivers and is a very effective way of communicating with motorists. Changeable message signs are capable of working in all weather conditions. Their visibility may be decreased in inclement weather conditions, however.

5. D. COMMENTS ABOUT CMS

Changeable message signs may be used to reduce speeds and improve traffic flow. This treatment is capable of displaying different messages upon need. One disadvantage is that changeable message signs are fixed objects, and when placed in work zones, may be struck by out-of-control vehicles.

6. RUMBLE STRIPS

6. A. EXPERIENCES WITH RUMBLE STRIPS

Pigman et al. (27) reported that adding rumble strips to existing traffic control setup reduced the percentage of traffic on
closed lanes from 11% to 4.1%. Richards et al. reported on the effect of using rumble strips in a two-lane two-way rural highway work zone (32) and in proving ground studies (31). Smith (34) discusses the use of rumble strips for speed control in city streets, and cited a study in Britain that showed rumble strips cause discomfort at a speed of about 25 mph.

6. B. EFFECTS OF RUMBLE STRIPS ON TRAFFIC

Rumble strips were not effective in reducing traffic speed significantly (27, 31, 32). Rumble strips reduced speed by 2 mph when they were placed in a work zone on a two-lane two-way rural highway (32). Proving ground studies (31) in the use of rumble strips were inconclusive. One study (27) reported that rumble strips were effective in improving lane distribution by decreasing the number of vehicles in a closed lane by 6.9%. Rumble strips have been effectively placed in advance of intersections for alerting drivers, consequently reducing speeds and accidents.

6. C. EFFECTIVENESS OF RUMBLE STRIPS

Use of rumble strips in construction zones has been very limited. The effectiveness of rumble strips is dependent upon the type of rumble strips placed and how well they will function under different traffic and weather conditions.

6. D. COMMENTS ABOUT RUMBLE STRIPS

Rumble strips may prompt drivers to pay more attention to the roadway, even though they may not reduce traffic speed.
Some motorists consider them unnecessary and annoying. Rumble strips may not function properly in ice and snow. There have not been many studies on the total effects of rumble strips on highway work zone speed and safety.

7. FLASHING BEACONS

7. A. EXPERIENCES WITH FLASHING BEACONS

Graham et al. (11) studied the effects of active warning of speed zoning in a rural freeway construction zone where the roadway was reduced to a two-lane two-way operation by means of a crossover section. The active warning of speed zoning consisted of high intensity flashing lights mounted on the regulatory or advisory speed zone signs. Lyles (20) conducted an experiment in a rural two-lane situation where one lane was closed. The short lane closure was staged to resemble a maintenance zone with one lane open during the day and two lanes open at night (there were no workers or flaggers present).

Goldblatt (8) developed a set of guidelines for installation of vehicle-activated flashing beacons for speed and speed limit control on curves. Koziol et al. (17) evaluated the effects of hazard identification beacons and speed violation signs in rural school zones and small communities.

7. B. EFFECT OF FLASHING BEACONS ON SPEED

In a study, flashing beacons were added to MUTCD construction
signs in a work zone in which one lane of a two-lane highway was closed (20). It was suggested that signs augmented with flashing beacons should be considered as an effective device for advance warning. In another study (11) the active warning of speed zoning did not effect speeds, but did reduce the erratic maneuver rate significantly.

Flashing beacons were effective in reducing traffic speeds when used at intersections or on curves (8) and in school zones or on approaches to small communities (17). Flashing beacons also increased drivers' awareness of roadside conditions (17).

7. C. EFFECTIVENESS OF FLASHING BEACONS

Flashing beacons alone are rarely used for speed reduction in construction zones. Flashing beacons get the attention of drivers when they are displayed and maintained properly. Effectiveness of flashing beacons would depend on the intensity and size of flashing beacons used. Flashing beacons used as an advance warning device may play a more significant role than as a speed reduction device. However, it is difficult to measure how much the driver's alertness is increased by flashing beacons.

7. D. COMMENTS ABOUT FLASHING BEACONS

Continuously flashing lights may lose their effectiveness when drivers get used to their presence. Flashing beacons connected to radar may be used as a warning device when a vehicle is speeding in a construction zone.
8. CONCLUSIONS

Flagging and law enforcement treatments were found to be the most effective in reducing vehicle speeds in construction zones. However, even these two methods did not reduce the speeds to the desired level. The effects of using the CMS, lane width reduction, rumble strips, and flashing beacons techniques were much less than flagging or law enforcement treatments. Applications of rumble strips and flashing beacons in construction zones speed reduction have been very limited. Therefore, their impacts are not fully known.

From the findings of the previous studies, it is difficult to generalize the effects of these treatments to all roadway and traffic conditions. Further studies on the effects of the variations of these treatments on different roadways and traffic conditions are needed. Effects of radar activated signs in construction zones also need to be studied.
REFERENCES


APPENDIX A

REFERENCE MATRIX
<table>
<thead>
<tr>
<th>REFERENCE NO.</th>
<th>AUTHORS</th>
<th>FLAGGING</th>
<th>LANE WIDTH REDUCTION</th>
<th>LAW ENFORCEMENT</th>
<th>CMS</th>
<th>RUMBLE STRIPS</th>
<th>FLASING BEACONS</th>
<th>ACCIDENT ANALYSIS</th>
<th>TRAFFIC MANAGEMENT</th>
<th>METHODS &amp; REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BOOKER, et al</td>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>STOP BAR, STOP/SLOW PADDLE</td>
</tr>
<tr>
<td>2</td>
<td>BURRITT, et al</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PILOT CAR</td>
</tr>
<tr>
<td>3</td>
<td>DUDEK, et al</td>
<td>W</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td></td>
<td>TCD, TCP, ADVISORY SPEED</td>
</tr>
<tr>
<td>4</td>
<td>DUDEK, et al</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td></td>
<td>TCD</td>
</tr>
<tr>
<td>5</td>
<td>DUDEK, et al</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>HIGHWAY ADVISORY RADIO</td>
</tr>
<tr>
<td>6</td>
<td>DUDEK, et al</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>REDUCED NO OF SIGNS</td>
</tr>
<tr>
<td>7</td>
<td>G A O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>GOLDBLATT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>B</td>
<td></td>
<td></td>
<td># ADVISORY SPEED</td>
</tr>
<tr>
<td>9</td>
<td>GRAHAM, et al</td>
<td>W</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TAPER FORMULA</td>
</tr>
<tr>
<td>10</td>
<td>GRAHAM, et al</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>GRAHAM, et al</td>
<td>W</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td></td>
<td>WARNING SIGNS, STRIPPING</td>
</tr>
<tr>
<td>12</td>
<td>HANSCOM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>HARGROVES, et al</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>REFERENCE NO.</td>
<td>AUTHORS</td>
<td>METHODS &amp; REMARKS</td>
<td>PROBLEM STATEMENTS</td>
<td>SPEED CONTROL</td>
<td># SPEED WARNING SIGNS</td>
<td>ALT SIGN SEQUENCE</td>
<td>SYNTHESIS</td>
<td>IMPLEM. GUIDE</td>
<td>SPEED REDUCTION</td>
<td></td>
</tr>
<tr>
<td>--------------</td>
<td>---------</td>
<td>-------------------</td>
<td>--------------------</td>
<td>---------------</td>
<td>----------------------</td>
<td>-------------------</td>
<td>------------</td>
<td>--------------</td>
<td>----------------</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>HARRIS</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>HUMPHREYS, et al</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>JACKS</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>KOZIOL, et al</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>LEVINE, et al</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>LYLES</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>NOEL, et al</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>NOEL, et al</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>NOEL, et al</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>NOEL, et al</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>NOEL, et al</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>NOEL, et al</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>PAULSON, et al</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td></td>
</tr>
<tr>
<td>REFERENCE NO.</td>
<td>AUTHORS</td>
<td>FLAGGING</td>
<td>LANE WIDTH REDUCTION</td>
<td>LAW ENFORCEMENT</td>
<td>CMS</td>
<td>RUMBLE STRIPS</td>
<td>FLASHING BEACONS</td>
<td>ACCIDENT ANALYSIS</td>
<td>TRAFFIC MANAGEMENT</td>
<td>METHODS &amp; REMARKS</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------</td>
<td>----------</td>
<td>----------------------</td>
<td>-----------------</td>
<td>-----</td>
<td>--------------</td>
<td>-----------------</td>
<td>-------------------</td>
<td>-------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>27</td>
<td>PIGMAN, et al</td>
<td></td>
<td></td>
<td></td>
<td>C</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td>SUPPLEMENTARY WARNING SIGNS</td>
</tr>
<tr>
<td>28</td>
<td>RICHARDS, et al</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SHIFTING / SPLITTING</td>
</tr>
<tr>
<td>29</td>
<td>RICHARDS, et al</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TCD/STRATEGIES</td>
</tr>
<tr>
<td>30</td>
<td>RICHARDS, et al</td>
<td>F</td>
<td>W</td>
<td>L</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>IMPLEMENTATION</td>
</tr>
<tr>
<td>31</td>
<td>RICHARDS, et al</td>
<td>F</td>
<td>W</td>
<td>L</td>
<td>C</td>
<td>R</td>
<td></td>
<td></td>
<td></td>
<td>SPEED REDUCTION</td>
</tr>
<tr>
<td>32</td>
<td>RICHARDS, et al</td>
<td>F</td>
<td>W</td>
<td>L</td>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SPEED REDUCTION</td>
</tr>
<tr>
<td>33</td>
<td>ROUPHAIL, et al</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TCD LAYOUT, SPEED</td>
</tr>
<tr>
<td>34</td>
<td>SMITH, et al</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td># BUMPS / UNDULATIONS</td>
</tr>
<tr>
<td>35</td>
<td>ULLMAN, et al</td>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PORTABLE SIGNAL</td>
</tr>
<tr>
<td>36</td>
<td>ULLMAN, et al</td>
<td>F</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>STOP/SLOW PADDLE</td>
</tr>
<tr>
<td>37</td>
<td>WARREN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td># SYNTHESIS</td>
</tr>
</tbody>
</table>

**LEGENDS**

A = ACCIDENT ANALYSIS  
B = FLASHING BEACON  
C = CHANGEABLE MESSAGE SIGNS  
F = FLAGGING  
L = LAW ENFORCEMENT  
M = TRAFFIC MANAGEMENT  
R = RUMBLE STRIPS  
W = WIDTH OF LANE IS REDUCED  
# = SIGN INDICATES THAT THE STUDY WAS NOT IN CONSTRUCTION ZONE
APPENDIX B

Summary of Literature on
Speed Control Methods in Work Zones

March, 1989

This study evaluated the effectiveness of using a reusable temporary stop bar (stop line) and a freestanding oversized stop/slow sign paddle, at a work-zone lane closure on a two-lane two-way highway, where flaggers were employed to control one-way traffic operation. The stop bar was 12 in. wide and 10 ft. long and was used to help drivers in deciding where to stop. One side of the stop/slow paddle was a 36 x 36 in. black-on-orange slow sign, and the other side was a 30 x 30 in. standard stop sign (R1-1). The flagger stood next to the sign and rotated it when needed. The paddle was mounted on two posts, and did not conform to the MUTCD standards. AADT of the highway was approximately 7000 vehicles per day. Flaggers with two-way radios were controlling traffic through the one-way section.

The three treatments to enhance flaggers' safety were: a) MUTCD set up (existing), b) the temporary stop bar added to the MUTCD set up, c) the oversized stop/slow paddle added to the MUTCD set up. Three types of data were collected: 1) distance between the flagger and the stopping point of the first vehicle in queue, 2) speed of vehicles which were approaching the work zone and were instructed by the flagger to proceed through the work zone without stopping, and 3) approaching speed of vehicles 3000 ft. in advance of the stop bar, at 500 ft. intervals. Each treatment was studied for about 2 hrs. in the open and closed lanes over a two-day period.

The data showed that the standard deviation of stopping distances were reduced when the stop bar or stop/slow paddle was used. The supplemental devices appeared to be especially useful in the open lane. Vehicle speeds approaching the work zone and going through the work zone did not change significantly among the three treatments. The authors proposed that for future study the stop bar be placed 30 ft. in advance of the flagger. The combined effects of the stop/slow paddle and the stop bar were not studied.


This construction zone traffic management study consisted of: a) a pilot-car operation (PCO), b) a communication system, c) a system approach to coordinate all flagging operations, and d) an umbrella contract to combine all traffic control functions under one authority.

Tests of PCO were conducted on three active projects, with combined project lengths of 3.6 miles. Data was not collected prior to using the test cars due to chaotic operational conditions. Thus, quantitative comparison was not possible, but qualitative comparisons (their observations) were made. After using the PCO, data on delay, travel time, headway, discharge time, queue length, and approach volume were collected. Two control points (one at
each end of construction zone) were used to hold queues of stopped cars until the opposing queues cleared the check points (operation was one-way between the check points).

There were two pilot cars, A and B. One pilot car was used to lead the queue, and the other one to trail the queue. The trailing pilot car reported to the leading pilot car if vehicles were straggled, stopped, or when gaps developing in queue warranted a speed reduction (no values given). Pilot car B, the trailing car, also had the responsibility of "fitting in" the contractor's equipment at the end of the queue. Each pilot car traveled about 200 miles per day. The leading pilot car had a folding sign that read "Pilot Car/Follow Me". The sign was folded when this PCO was operating as the trailing car.

The control section was divided into 10 equal segments (spacing 0.36 mile), with signs installed so that cars A & B could report the time at which they reached a pre-designated point. Radios were supplied to the test cars and the project traffic control supervisor (TCS), who controlled the flaggers' activities. The flaggers did not control through traffic, but allowed the construction equipment to enter into the traffic stream at appropriate times. The flaggers were stationed at points where the contractor's equipment was entering onto the highway.

The data collected was used to develop a logical relationship between approach volume and maximum service flow rate. The model showed that the approach volume began to exceed the service rate when volume was about 600 vph.


This report contains four chapters and an introduction. Chapter 2 is a summary of report FHWA/TX-86/58+321-1 entitled "Catalog of Traffic Control Strategies and Devices." Chapter 3 summarizes current district practices regarding traffic control plans (TCP) and problems related to TCP in Texas.

Chapter 4 summarizes the results of field studies at three major freeway reconstruction projects, which were performed in order to evaluate the effectiveness of some aspects of TCP. One of the projects was the construction of the Pratt I interchange in San Antonio, Texas, which lasted about four years. It was recommended that 11 ft. lanes be used and portable concrete barriers (PCB) be placed at least 1 foot from the edge of the narrow lanes. Detours were modified to have a maximum curvature of 6 degrees (these were called "soft" detours). Advisory speed signs with "odd-ball" speeds (e.g. 17 mph, 26 mph) at several detour curves were used. The signs were noticed by drivers, but did not slow the drivers down to the posted speeds.

Accident analyses showed that fatality and injury rates in this construction zone were lower than fatality and injury rates for all accidents in Texas in 1977. The accident data used for comparison was collected in 1980-1983, but was compared to the 1977 data because 1977 statistics were readily available from another
report. The rate used was injuries or deaths per 10,000 accidents. The reason given for lower rates is the attention given to the TCP in this site. Interestingly, 9% of the accidents at this site were alcohol related while there were only 1% alcohol related accidents for all the Texas work zone accidents in 1977.

The second project was Katy Freeway, which was under construction for the installation of an Authorized High Occupancy Vehicle Lane (AVL) in the median section of the freeway. Accident rates for this site during construction were higher compared to the before-construction conditions. A comparison of speeds for before- and during-construction conditions showed a difference in speeds only at one out of five segments. The overall operating speed did not change significantly. Traffic volumes of up to 1840 vphpl were sustained on lanes as narrow as 10 feet.

The third project was the North Freeway, which was under construction for replacement of contra-flow lane with AVL lanes. No accident analysis was done for this site. Traffic volumes as high as 1757 vphpl (1820 pcphpl) were observed on lanes 10-11 ft. wide.

The development of a special traffic handling crew in District 12 was discussed in Chapter 5 of the report.


This article is a summary of the report called "Improvements and New Concepts for Traffic Control in Work Zones, Vol. 1 - Effects of Traffic Control on Four-Lane Divided Highway", TTI, 1983.

Nine field studies were conducted to evaluate the effects of a single-lane closure in one direction versus a crossover with two-lane two-way traffic operation (TLTWO). The variables studied were: workers' productivity, job duration, construction costs, TCD cost, highway-user cost, accidents, conflicts and capacity. Due to limited data, no conclusion was made on which alternative method offered cost savings over the other.

Data on volume, speed changes, vehicle mix, and occupancy were collected on four single-lane closures and five TLTWO. Productivity was measured indirectly by considering project duration and construction and road-user cost relationships. Actual traffic control costs ranged from 4% to 39% of total construction cost, with an average value of 15%. Highway-user costs were calculated using the QUEWZ model. An exponential curve showing additional delay versus demand volume was fitted to the data points.

Accident data for at least one year before construction and for the entire duration of construction activities were analyzed. The accident data for the construction period was for 1.2 months on one construction site, and 10.6 months on another site. Note that the accident rates for the two sites were for short periods of time. The percentage in accident/100 MVM ranged from +64% to -34%,
most of which showed an increase. The rate of vehicle-traffic-control-device conflict on the right lane was higher than the left lane, and for both lanes the rate was higher at moderate volume levels.

Capacity in the crossover direction was 1450 vph (for site 6) and 1720 vph in the opposite direction. Thus, capacity in the crossover direction was about 300 vph lower than the opposite direction. For single-lane closure, the capacity was 1780 cars. (Average axle per vehicle was 2.19 - 2.22, which was used for conversion of raw count to vph).


This report presents the findings of field studies which were performed to determine the feasibility of using CMS and highway advisory radio (HAR) for freeway maintenance operations. The CMS was used effectively to direct traffic or encourage traffic to leave the closed lane at a lane closure work zone on I-35 in San Antonio, Texas. A specific diversion message was more effective than a general diversion message.

A Highway Advisory Radio (HAR) was used at a major maintenance zone on a rural interstate highway in Chambers County, Texas. HAR had little or no effect on traffic operations because (a) signing of the work zone was excellent and HAR functioned as a source of supplemental information, and (b) the signs used to encourage drivers to tune to HAR were apparently inadequate in terms of legibility and visibility.


For short duration maintenance operations (less than 20 min) on four-lane divided highways with AADT < 30000, configurations with reduced number of traffic control devices were developed and evaluated. The hypothesis was that an arrow board located upstream of a work zone would be the primary source of information for drivers and the other TCD would supplement the arrow board. Five setups with fewer advance warning signs were evaluated in the field and results were compared to the Texas MUTCD setup for minor maintenance operations. The study attempted to determine if using cone a taper with an arrow panel is necessary. Texas MUTCD requires three static advance warning signs, a cone taper, and an arrow board placed behind the cone taper in the closed lane.

The candidate setups were evaluated with and without the cone taper in place in advance of the work zone lane closure. The candidate setups were: (1) "ROAD WORK AHEAD," (2) "RIGHT/LEFT LANE
CLOSED AHEAD," (3) symbolic lane closure sign, (4) CMS displaying the messages of candidate setups 1 and 2, and (5) A large (7x7.5 ft.) "LANE BLOCKED" sign.

The traffic volume data was collected at five stations. Stations 1, 2, 3, 4, and 5 were located at 0, 500, 1000, 1500, and 2500-3000 ft., respectively, from the beginning of the cone taper. Also, video recordings were made at a section just upstream of the cone taper. The proportion of traffic volume on the closed lane was used as the primary measure of effectiveness (MOE). If the proportions at stations 2, 3 and 4 were as low as the values observed for the Texas MUTCD setup, then the candidate was considered effective. A second MOE used was severe erratic maneuvers, such as impact with the cone or TCD, and severe braking or skidding. The five candidate setups were tested at six sites with the left lane closed and six sites with the right lane closed. They abandoned field studies of signing without the presence of cone taper.

Data analysis indicated that CMS and "LANE BLOCKED" signs were more effective in influencing drivers to exit the closed lane than the Texas MUTCD setup. The symbolic lane closure signs were as effective as the Texas MUTCD setup. The "ROAD WORK AHEAD" sign was least effective. No difference on erratic maneuver rate was observed. The study recommended use of CMS or the LANE BLOCKED sign.


This is a General Accounting Office report on the evaluation of the conditions of work zones. The GAO visited 26 construction work zone sites and reported that the design of highway work zones varied from project to project and from state to state. The report highlighted that there are competing priorities with the highway officials, and the completion of the project on time and budget outweighed the safety aspects. There was a need for state supervision of work zones in order to have proper control over the placement, relocation, and renewal of traffic control devices during the progression of work.

Another point highlighted in the report is that the construction reports which contain information on the progress of work do not mention much about the safety conditions of the construction work zones, thereby making higher officials unaware or uninformed. The GAO group found that night-time supervision was noticeably lacking in the construction work zones. The need to make nighttime inspection of the work zones was emphasized.


The objective of this study was to develop a set of guidelines
for installation of certain classes of flashing traffic control devices. The devices were continuous-flashing and vehicle-actuated STOP intersection beacons, STOP AHEAD beacons, and vehicle-activated beacons for speed and speed limit control on curves. Note that these devices were not used in construction zones.

For speed control on horizontal curves, the devices consisted of two flashing beacons 12 inches in diameter, drawing attention to the message "WHEN FLASHING TOO FAST FOR CURVE". The activation device (two loop detectors) was located 275 ft. upstream of the flashing beacon.

Along the road the speed limit was reduced from 40 mph to an advisory speed of 30 mph over a section 1100 ft. in length. The speeds were measured at three points: at a point 30 ft. upstream of the speed detectors, at the location of the sign, and at a point located 120 ft. downstream of the sign.

This setup was evaluated at two locations and the results of the experiments are as follows:

<table>
<thead>
<tr>
<th>PROJECT NAME</th>
<th>Point 1</th>
<th>Point 2</th>
<th>Point 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>BARRINGER DRIVE</td>
<td>8%</td>
<td>19%</td>
<td>16%</td>
</tr>
<tr>
<td>PARK ROAD</td>
<td>5%</td>
<td>1%</td>
<td>-7%</td>
</tr>
</tbody>
</table>

Note that on Park Road there was a speed increase at Point 3; and, the author felt that this was due to the fact that the end of the curve was visible from point 3.

For speed limit control two flashing beacons were used, one on each side of a warning sign which read "SPEED VIOLATION WHEN FLASHING". The results of using such a sign in the town of Palmyra, Maine showed a decrease in speed ranging from 24% to 11%. In the Charlotte, NC, experiment, the signs significantly reduced the mean speed and 85th percentile speed, but had little effect on speed variance.


This study evaluated the effectiveness of a proposed taper length formula that gives a shorter taper length than the standard MUTCD method for speeds below 60 MPH. The proposed formula was evaluated at four construction zones during the day and night. The proposed length of taper (L) is computed from the formula: \( L = WS(S/60) \), compared to the MUTCD formula, which is: \( L = WS; \) where \( S \) is speed and \( W \) is the lane width.

At Site 1, the effects of funneling and reducing width of traveled way at the approach to the construction zones was studied (no values are given). Site 1 was a right-lane closure of a four-lane undivided urban arterial. The effect of funneling and lane
width reduction on speed was not significant.

The speeds were measured at the following locations: (1) upstream of the beginning of the zone, (2) on the approach to the work zone, (3) in the entrance to the transition area, and (4) in the work area. Arrangements were made in the transition area to record information on lateral placement of the vehicle. One of the observers stationed at the transition area recorded vehicle conflict and erratic maneuvers.

Four general measures of effectiveness were considered in the taper length studies: (1) mean speed, (2) traffic conflict rates, (3) erratic maneuver rate, and (4) centerline encroachment rate.

An analysis of variance technique was used to interpret the data. The analysis indicated that speeds were slightly higher for the shorter length tapers. The observations with the very short tapers also showed a sudden decrease in speed near the end of the taper. The results from the erratic maneuver analysis were mixed. The slow moving conflict rates did not increase at any of the test sites. The proposed taper length, with no funnelling, depressed the slow moving conflict at Site 1.

There was no indication that buses or trucks encroached on the adjacent lanes when the proposed taper length was used. Later on, the proposed taper formula was included in MUTCD to be used in urban, residential, and other streets where the posted speeds are 40 mph or less.


The focus of this paper is on the effectiveness of work zone accident data process (WZADP) during its trial implementation in Iowa and North Carolina. The goal was to reduce accidents by identifying potential hazards and problems, and correcting them. During the trial implementation, data from 40 projects in Iowa indicated that accident rates during construction were lower, in case of primary route projects and at intersections, than the accident rates before the construction activity started. However, the accident rates on interstates increased during construction. The data revealed that most of the work zone accidents occurred in the work area.


The first part of this report is about accident analysis and the second part is about evaluation of speed reduction methods. Data from 79 construction projects in seven states were used to study accidents before and during construction. Comparison of before and after accident frequencies, accident rates, regression analyses of construction zone characteristics versus accident rates; and case studies of three construction sites were made.
Accident rates were computed using the traffic volume for the "before" construction period (traffic volume was not available for during construction). The mean construction accident rates varied from 116 to 427 accidents/100 MVM. The rate for urban roads was higher than that for rural roads. Tables quantifying effects of the type of construction, work area, and type of lane reduction were given. Projects with reduced lane width experienced a 17.6\% increase in accident rate during construction, while projects with normal width had only a 6.6\% increase in rates.

The study concluded that construction zones caused an increase of 1.6 accidents/month. The mean accident rate increased by 6.8\% and the total number of accidents increased by 7.5\%. Thirty-one percent of the projects studied experienced a decrease in accidents during construction, while 24\% experienced a rate increase of more than 50\%. Accident frequency analysis showed a substantial increase in fixed object, head-on, and rear-end accidents, with a decrease in run-off-road and side-swipe accidents. Projects with speed reduction had higher monthly accident differentials than those without speed reductions. The accident rate analysis showed that, those projects with speed reductions had a slightly higher accident rate increase. Time-trend analysis of accidents indicated that accident experience in the first month after beginning of construction was not significantly different from the other months of construction; and, that construction zones do not have better accident records over time. The regression analysis showed that there is a negative correlation between the length of construction zone, duration of projects, and the accident rate. Thus, the longer a project (both in time and space), the lower the accident rate. Accident rate analysis showed that bridge work followed by reconstruction of existing roadway (on the same alignment) experienced the largest percentage accident rate increase. Construction zones with reduced speed limits do not have a lower accident rate than other work zones. Field studies showed that speed zoning did not reduce mean vehicle speed, but increased vehicle conflicts in the taper area.

Three sites (one urban street, one urban freeway, and one rural freeway) near Kansas City were selected for the speed reduction studies. The urban street was a two-lane undivided arterial, and bridge deck repair reduced the number of lanes to one, and then a detour onto an adjacent two-lane street. The speed limit was 45 mph before construction and 30 mph during construction.

The urban freeway was reduced from two lanes per direction to two-lane two-way operations because of resurfacing and widening of a bridge. The speed limit was 55 mph before construction, and was reduced to 45 mph ahead of construction and 35 mph at the lane taper (advisory sign) during construction. Effects of advisory and regulatory speed zoning (55 mph, 45 mph, 35 mph), transverse striping, and obliteration of nonapplicable pavement marking were evaluated.

The rural freeway, similar to the urban freeway, was reduced to a two-lane two-way operation by means of a crossover section. The speed limit was reduced from 55 mph to 40 mph at the crossover. Effects of advisory and regulatory speed zoning, law enforcement,
sequential flashing arrows, and active warning of speed zoning were tested. Enforcement was made by a highway patrolman or a sheriff stationed on the roadside. Active warning of speed zoning consisted of high-intensity flashing lights mounted on the regulatory or advisory speed zone signs.

At the urban street, taper lengths of \( L = WS \) and \( L = WS^2/60 \) were compared and effects of funnelling and lane width reduction were examined. Speed, volume, and headway data were measured by tape switches placed on pavement and connected to a recorder. Radar was also used to measure speed. Results for urban streets were not given in the report.

From the speed reduction study they concluded that speeds were lower at night and vehicles slowed as they transversed the zone. Speed zoning had no effect on speed in rural freeways and it increased the conflicts in the transition areas. The enforcement reduced the mean vehicle speed by 2.77 mph and the reduction was greater near the enforcement vehicle. The arrow panel reduced speeds near the panel. The active warning of speed zoning did not effect speeds. No effect on speeds from transverse striping or nonapplicable lane lines could be determined. The ANOVA technique was used to make inferences about the data (data from one of the experiments from the urban freeway was lost).

An erratic maneuver was defined as a single vehicle suddenly swerving or braking when approaching a transition area. Erratic maneuvers were higher at night. The arrow panel, warning of speed zoning, and enforcement reduced the erratic maneuver rate significantly. Speed zoning had no effect on erratic maneuver rate.


This study reported on the effect of CMSs on highway lane closures and compared its effect with a base condition with no CMS. Both speed and lane distribution data were collected at 4 points: 1) approximately one mile before lane closure (advance), 2) either at 2000 ft. or 0.75 miles in advance of the taper, where the CMS was placed (CMS point), 3) midway between CMS and taper (intermediate), and 4) a point 100 ft. in advance of the first taper channelizing device.

The CMSs tested were the 1, 2, and 3 line type and the display was a rotating drum or a bulb matrix type. The three placement alternatives tried out were: a) one CMS at 0.75 miles, b) one CMS at 0.75 miles, and another at 2000 ft., and c) one CMS at 2000 ft. The messages used were: 1) speed and closure advisory, (2) speed and merge advisory, 3) merge and closure advisory, and 4) closure advisory. It was found that in every case in which a CMS was used there was better lane distribution with drivers changing to the through lane before they approached the work zone, compared to the lane distribution without a CMS. It was observed that there was a speed reduction of 7.0 to 7.6 mph at the taper when a CMS was used, compared to when no CMS was at the work zone. There was no
significant difference between the effect produced by the three different types of CMS devices (e.g. one-line bulb vs two-line rotary). The 0.75 mile location gave a slightly better speed reduction compared to other CMS locations.

Responses of 489 drivers to a questionnaire were obtained. The purpose of the questionnaire was to gather information about drivers' detection, recognition, and comprehension of the CMS devices. Drivers were not aware that they were participating in a work zone related study until they had answered a major portion of the questionnaire. The responses from the questionnaire were analyzed to access the human factor aspects of the signs. It was found that there was a general tendency to say "the adequacy of the warning system was sufficient," and "the signs were helpful." Among the different messages used, the use of speed and closure advisory messages was generally preferred. There was an unfavorable response to the message "LANE CLOSURE AHEAD" when it did not specify which lane was closed. The three line signal was found to be the most acceptable to the drivers. The paper suggested that cost-efficient CMS use would be at a minimum when traffic volume was 900 vph and when sight distance is limited.


The authors took a comprehensive look at all work zone accidents to determine the magnitude and characteristics associated with moving vehicles around and through the highway work zone. They studied 2127 reported work zone accidents in Virginia in 1977 (82% of all work zone accidents in the year 1977). They made numerous conclusions by comparing the data for work zone accidents with the data for all accidents for the state in the same year. Some of the results are as follows.

Accidents in work zones peaked in the week day, and not on weekends as in normal driving conditions. Accidents caused by bad surface conditions were mostly attributed to the work activities on the work zones. Twenty % of work zone accidents involved large vehicles compared to 15.7% for normal roadways. An examination of the accident reports showed that this was due in part to involvement with construction equipment in work zones accidents.

It was pointed out that 16.2% of "fixed object hit" accidents involved construction equipment. Most of the accidents were due to unsafe movement of a work vehicle. Sixty-five % of the accidents were recorded as drivers' negligence or inattention, and speeding was listed as the causes in only 6.1% of the accidents. In 17.2% of the accidents some particular aspect of the work zone was cited as the primary cause of the accident. The unexpected presence of a flagman or construction sign was noted as a problem. This study found that younger drivers were less involved in work zone accidents than older drivers. This tendency could be interpreted as an indication that younger drivers are more alert, or better able to handle unforeseen situations that may be found in work zones.
An examination was also made of the distribution of vehicle speeds for both work zone and all 1977 accidents. This comparison showed that there was an over-representation of work zone accidents involving slow moving vehicles (40.1% of work zone vehicles traveling less than 15 mph compared to 36.4% for all 1977 accidents.)

It was also determined that excessive speeds were present in 13.1% of all Virginia accidents. This is slightly less than the nationwide average of 14.6% which is dramatically less than the 58.3% found by Nemeth and Migletz in the Ohio study which studied only high speed highways in rural locations.

They concluded "that approaching motorists are generally not prepared for the interruption to free flowing traffic typical in many work areas."


This article shows the industry's concern on the rate of accidents in construction work zones. It cites experience of the California Department of Transportation as an example, where with better management of the construction work zone they were able to bring down the accident rates from 132% above normal, to about 7%, and fatality rate from 21.4% to 1.4% above normal roadway rate. The points and observations collected in this article on accident statistics, aging drivers, and reflective materials are supported by findings from other publications.


Site visits to 103 work zones in 11 states were made to identify and prioritize construction zone problems. Case studies considering before and during accident experiences at 30 construction sites were also conducted. Almost 200 articles were identified. Abstracts were prepared for 48 of the studies. A subject matrix was also prepared. Results of the literature review indicated that maximizing compliance of traffic control plans with MUTCD requirements would improve traffic operation performance and would reduce accidents.

Accident data for 30 construction sites out of the 80 sites used by Midwest Research Institute, FHWA/RD-77/80, were used for a detailed analysis. Collision diagrams of accidents during the construction indicated that a concentration of accidents, generally occurred at the point of entry into the construction zone, at median crossovers, and at at-grade intersections. Rear-end accidents were the most common type (50% of total).

As a result of the site visits, overall traffic operations were rated as "poor" at 10% of construction sites. A total of 618
individual problems or deficiencies were identified by a panel of six research staff after reviewing documents gathered during the site visits. About two-thirds of the problems were already addressed and could be eliminated by using existing knowledge. Problem statements were prepared for 20 general topics.

Work zone traffic control system deficiency, use of non-standard TCD, and inappropriate use of TCD were common in work zones. The staff estimated that 43 sites (42% of sites) out of 103 work sites visited had safe speeds of less than the speed limit in effect at that site.


The number of fatalities occurring in work zones rose from 489 in 1982 to 702 in 1984. This 44% increase coincided with the major increase in rehabilitation work on the Interstate system due to the Surface Transportation Act of 1982. Work zone fatalities in 1985 were 680.

From survey responses of 46 states on work zone problems in Interstate and Federal-aid primary systems, it was found that 73% of the work zone fatalities occurred in construction zones, 14% on maintenance, 2% on utility, and 11% on other type of work zone activities. (Maintenance and utility work often lasted one day or less). The survey showed that on Interstate and primary systems there was an estimated 46,400 fatalities in 1985 nationwide. Of these accidents 400 were fatal, resulting in 485 fatalities, 15,000 were non-fatal injury accidents and 31,000 were property damage only. The survey revealed that 64% of all work zone fatalities occurred in rural areas, while 66% of work zone injuries and 71% of all work zone accidents occurred in urban areas. Sixty percent of all work zone accidents were of the type where one vehicle strikes another vehicle. This is the most common type of work zone and non-work zone accident. The second most common type of work zone accident was the fixed object collision type, accounting for 20%.

The Interstate system accounts for 10% of all fatalities. However, about one-third of work zone fatalities occurred on the Interstate system. Work zone accidents were also more severe than non-work zone accidents. Darkness was a major factor contributing to fatal accidents in the work zones.

Pedestrian accidents were identified as a problem in the work zones. The proportion of pedestrian fatalities in work zones accidents was about the same as in all fatal accidents. In rural work zones, 80% of the pedestrian fatalities occurred during daylight.

Fatal accidents involving tractor-trailers were higher in work zones than non-work zones. (No number for work zone is given; for non-work zone it is 10% of the fatal accidents).

This study evaluated the effectiveness of new sign configurations on speed reduction in school zones and on approaches to small communities. For the school zone experiment, six new sign configurations were tested in seven sites, three states, and on high-speed two-lane highways. The speed violation sign was activated when a vehicle exceeded the speed limit by more than five mph (at sensor location 3). Sensor 1 was located ahead of the school signs, Sensor 2 was adjacent to the school advance sign, and Sensors 3 and 4 were at the entry and exit points to the speed zone. Spot speed, speed on a section, 85th percentile of section speeds, and percent compliance were recorded. Also roadside interviews were conducted to examine the understanding of signs and to obtain information about driver characteristic.

For the small community experiments, three new sign configurations were tested at two sites in Mississippi. A roadside interview similar to the school zone experiment was also conducted. They concluded that hazard identification beacons and speed violation signs were effective in reducing speeds and increasing driver awareness of the roadside conditions. The combination of signs with hazard identification beacons and the speed violation signs seems to offer the highest potential in reducing speed and increasing driver awareness. Signs with hazard identification beacons were most effective but did not always result in substantial improvement. "Passive signs were ineffective for informing drivers of existing speed limits." Although the signs were effective when compared to the base condition, they did not result in a reasonable degree of compliance to the posted speed limits. Speed reductions as high as 6 mph in the small community experiment, and as high as 5 mph for school zones were achieved.


During 1980 and 1981, 12 highway workers were killed and 34 injured in the Houston, Texas, area alone, which is more than the loss of the police and fire department put together. Drunk drivers and speeding motorists were the cause of most of the casualties. Because of these statistics, highway workers believe that they are much safer when a long queue of vehicle moves slowly past the work zone. The study identified the following countermeasures which increase work zone safety: a) Public oriented measures, such as finding optimum time for construction, number of lanes to be closed, traffic control plan approval, and informing public; b) worker oriented safety measures, such as truck mounted impact attenuator; c) enforcement measures, such as hiring off duty police officers; and d) a special traffic handling crew, i.e. a trained crew was assigned the task of handling traffic during
maintenance activities. They also mentioned that speed enforcement studies indicated that, there may be beneficial effects from speed enforcement on one day on succeeding days when no enforcement is present.


The effectiveness of five experimental sign treatments for controlling drive speeds in the vicinity of hazardous horizontal curves on rural two-lane highways is reported. The sign ranged from the standard curve warning arrow to a regulatory speed zone in conjunction with the curve warning. Speed, vehicle classification, centerline and edge line crossing, and vehicle registration data was collected at two sites where the posted speed limit was 45 mph. The analysis of data revealed that no sign or grouping of signs was consistently more effective than another in decreasing potential hazard at horizontal curves in rural two-lane roads.


Two experiments were conducted in central Maine to examine effectiveness of several alternative sign sequences for warning motorists about construction and maintenance activities in a rural, two-lane situation where one lane was closed. The long zone (long lane closure) was reconstruction of a bridge deck where one lane was kept open. The short zone (short lane closure) was staged to resemble a maintenance zone with one lane open during day and two lanes at night (there were no workers or flaggers present). In one sign sequence, two 8 in. yellow flashing beacons were added on top of the MUTCD standard construction zone diamond sign. For the long zone, a traffic signal was added to allow traffic to move alternately through the one-way section. For short and long zones sequences of symbolic signs were also used.

Speed data were collected at different points before the work area (speed profile). A plot of speed vs distance from the lane closure showed that the signs augmented with flashing beacons were effective in reducing speed over a part of the section. The symbol signs were as effective as the standard MUTCD signs. The traffic signal dominated the effect of other signs as the motorists got closer to the one-lane section. No abrupt motorist reaction due to the sign sequence was observed. The sign augmented with flashing beacons should be considered as an effective device for advance warning.

An extensive review of research on traffic safety in work zones was conducted. The findings are presented in the following four categories: a) work zone accident experience, b) safety performance of information and guidance systems, c) safety performance of barriers, and d) traffic management schemes. Synthesis of 70 research projects on these areas was provided.


This article, in general terms, discusses traffic control at work zones using the MUTCD regulatory and warning sign. Effects of flagging and law enforcement on speed reduction were mentioned. They stated that speed reduction should be based on needs and should not be misused. Otherwise, the credibility of the traffic control signs will be damaged.


This paper looked in detail at the nature of accidents in work zones. The accident analysis was based on the premise that traffic control at work zones on the Ohio Turnpike is of uniformly high standards and therefore most accidents would be driver error related. There was a total of 185 accidents on the Turnpike during the 28-month study period. They divided the work zone into the following sections: 1) advance zone - section between the first advance warning sign and the taper - which had 12 accidents, 2) taper zone - zone where the lane width is reduced- which had 17 accidents, 3) single lane zone, which had 43 accidents, 23 of these accidents involved trucks (vehicle type at fault); 4) crossover zone, with 69 accidents; and 5) bi-directional section with 41 accidents. There were nine accidents for which the accident location could not be determined.


This report provides an implementation guideline and presents long-term results of four speed control techniques evaluated on six-lane freeway construction zones. The techniques are: a) MUTCD flagging, b) innovative flagging (MUTCD plus pointing to speed
limit sign), c) a marked police car with cruiser and radar on, and d) a uniformed police officer controlling traffic. Each technique was applied for a period of 10-15 days. For the field evaluation results, one may refer to a paper in TRR 1163, 1988, by the same principal authors.


This study evaluated the short term (a few days) and long term (10-15 days) effectiveness of implementing four speed reduction techniques on multi-lane freeways. The results reported in this paper are also reported in FHWA/IP-87/4 by the same principal authors. The techniques evaluated are: a) MUTCD flagging, b) innovative flagging (flagging + pointing to speed limit sign), c) a marked police car, and d) uniformed police office standing to control traffic. Each technique was applied continuously for a period of 10-15 days on six-lane freeways to examine long term effects of the techniques. These treatments were tested for short term (1-2 hours) and had shown to be effective (see Richards, et al., 1985.)

Four sites (each site had two kinds of lane closures) on I-495 in the suburb of Wilmington, Delaware, were selected. On each site, either the left and center lanes were closed (Phase 1) or the right lane was closed (Phase 2). Speeds were measured at three stations (points). Station A was located approximately 5000 ft. ahead of Station B which was at the beginning of the taper. Station C which was at the end of the taper (beginning of a section with reduced no. of lanes) and was 2500 ft. in Phase 1, and 4500 ft. in Phase 2, further down from station B.

Each treatment was applied at one location for Phase 1 and Phase 2 (there were four locations and four treatments and each treatment had Phase 1 and 2). Data were collected for about three hours on weekday, off peak, daytime, and under dry pavement conditions. Volume, speed, and vehicle classification data were collected using VC 1900 Traffic Analyzers.

Data were collected at stations A, B, and C prior to implementation, within three days of implementation, and 10-15 days after implementation. For each treatment and speed station, at least 100 speed observations per lane were made.

One-way ANOVA was used to compare speeds among the treatments. The effect of driver population difference is taken into account, and net changes in speed between stations A and C were computed. Two-way ANOVA was then used to check the effects of site, treatment type, and their interaction. If there was a difference in net speed change, they used Shaffe's test for multiple comparisons.

They discussed the effects of short and long term exposure at stations B and C. The results for short and long term periods are summarized in Table 1. They concluded that police radar and police controller were effective in short and long term (at station C)
Table 1

Short-term (within 3 days) and long-term (10-15 days) net speed changes between station A and C, and stations A and B when one or two lanes out of three lanes of a freeway are closed. (This table is created using the data from Noel, E.C., et al, TRR 1163, 1988).

<table>
<thead>
<tr>
<th>TREATMENT</th>
<th>ONE LANE OPEN</th>
<th></th>
<th>TWO LAKES OPEN</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SHORT TERM</td>
<td>LONG TERM</td>
<td>SHORT TERM</td>
<td>LONG TERM</td>
</tr>
<tr>
<td></td>
<td>A→C</td>
<td>A→B</td>
<td>A→C</td>
<td>A→B</td>
</tr>
<tr>
<td>ALL VEHICLES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MUTCD Flagging</td>
<td>-4.7</td>
<td>+6.7</td>
<td>-3.8</td>
<td>+3.3</td>
</tr>
<tr>
<td>Innovative Flagging</td>
<td>-3.6</td>
<td>-6.4</td>
<td>-3.0</td>
<td>-6.7</td>
</tr>
<tr>
<td>Police Controller</td>
<td>-5.3</td>
<td>-6.3</td>
<td>-3.3</td>
<td>-6.8</td>
</tr>
<tr>
<td>Police Radar</td>
<td>-4.0</td>
<td>+3.6</td>
<td>-6.4</td>
<td>-5.4</td>
</tr>
<tr>
<td></td>
<td>+2.6</td>
<td>+0.2</td>
<td>+0.8</td>
<td>+4.4</td>
</tr>
<tr>
<td></td>
<td>-1.7</td>
<td>+1.4</td>
<td>+1.4</td>
<td>-0.3</td>
</tr>
<tr>
<td></td>
<td>-3.5</td>
<td>-5.1</td>
<td>-3.3</td>
<td>-2.3</td>
</tr>
<tr>
<td></td>
<td>-4.0</td>
<td>-2.4</td>
<td>-8.4</td>
<td>+0.5</td>
</tr>
<tr>
<td>CARS ONLY</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MUTCD Flagging</td>
<td>-4.4</td>
<td>+5.9</td>
<td>-2.3</td>
<td>+4.0</td>
</tr>
<tr>
<td>Innovative Flagging</td>
<td>-3.9</td>
<td>-6.7</td>
<td>-3.2</td>
<td>-6.5</td>
</tr>
<tr>
<td>Police Controller</td>
<td>-4.6</td>
<td>-6.3</td>
<td>-3.5</td>
<td>-6.0</td>
</tr>
<tr>
<td>Police Radar</td>
<td>-3.5</td>
<td>+3.7</td>
<td>-5.8</td>
<td>-5.0</td>
</tr>
<tr>
<td></td>
<td>+2.8</td>
<td>-0.1</td>
<td>-0.4</td>
<td>+3.3</td>
</tr>
<tr>
<td></td>
<td>-2.4</td>
<td>0.0</td>
<td>+1.2</td>
<td>-1.3</td>
</tr>
<tr>
<td></td>
<td>-2.3</td>
<td>-4.3</td>
<td>-2.4</td>
<td>-1.1</td>
</tr>
<tr>
<td></td>
<td>-3.7</td>
<td>-2.6</td>
<td>-8.7</td>
<td>+0.3</td>
</tr>
<tr>
<td>TRUCKS ONLY</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MUTCD Flagging</td>
<td>-7.2</td>
<td>+6.4</td>
<td>-10.6</td>
<td>-0.8</td>
</tr>
<tr>
<td>Innovative Flagging</td>
<td>-2.9</td>
<td>-4.6</td>
<td>-0.8</td>
<td>-4.3</td>
</tr>
<tr>
<td>Police Controller</td>
<td>-4.8</td>
<td>-5.5</td>
<td>-1.5</td>
<td>-9.3</td>
</tr>
<tr>
<td>Police Radar</td>
<td>-5.9</td>
<td>+3.5</td>
<td>-4.1</td>
<td>-1.5</td>
</tr>
<tr>
<td></td>
<td>+3.8</td>
<td>+4.1</td>
<td>+6.2</td>
<td>+9.5</td>
</tr>
<tr>
<td></td>
<td>-3.4</td>
<td>+3.3</td>
<td>+0.1</td>
<td>+1.8</td>
</tr>
<tr>
<td></td>
<td>-4.4</td>
<td>-6.9</td>
<td>-4.9</td>
<td>-7.0</td>
</tr>
<tr>
<td></td>
<td>-3.1</td>
<td>+0.1</td>
<td>-6.4</td>
<td>+2.1</td>
</tr>
</tbody>
</table>
experiments. It was stated that "From a practical sense, however, one cannot say that the police radar and police controller were better than innovative flagging." The effectiveness of the treatments appeared to depend on the number of lanes that remain open to traffic in the work area. The flagging techniques were effective in multi-lane freeways with one lane open to traffic.


This paper refers to a study in 1965 in California where ten randomly selected construction projects were studied, and accident rates before and during construction were compared. The accident rate increased by 21.4% during construction and the fatal accident rate went up by 132.4%. However, in 1970, another study of 31 projects was conducted after improving the work zone traffic control practices, which showed only a 7% increase in accident rate and 1.6% increase in the fatal accident rate, demonstrating the strong influence of traffic control practices on construction work zones, and emphasizing the need and potential for improvement in traffic control practices.

Table 1 also refers to the National Safety Council's statistics which reported that highway workers experience 1.7 times the all-industry average of work injuries per million person hours worked. Street and maintenance workers in municipalities experienced five times the all-industry averages.

Improvements were suggested on (1) effective planning and designs of the work zones and (2) effective management and operations of construction work zones. They suggested the following procedure for improvement in the work zone conditions.

1) PLANNING
   (a) Collection of roadway, traffic, and construction data.
   (b) Selection of basic work zone type and scheduling.
   (c) Formulation of speed control strategy.
   (d) Determining of geometric design elements.
   (e) Selection of traffic control devices and methods.

2) MANAGEMENT
   (a) Improve public information.
   (b) Training of field personnel.
   (c) Review and modification of traffic control.
   (d) Removal of inappropriate devices.
   (e) Improve maintenance of traffic control devices.


This study evaluated the effectiveness of supplemental traffic control devices, placed in advance of construction zones, on the
flow of traffic in the northbound and southbound directions of a lane closure on I-75. The new devices evaluated were: supplemental lane closure warning signs placed at 5, 4, 3, and 2 miles before the taper; variable message signs placed at 2 miles and 1 mile before the taper; and rumble strips at 1.5, 1.0, 0.6, 0.3, and 0.1 miles before the taper. They studied the merging patterns of traffic as they encountered the lane closure in the work zone. Observers were positioned at the following four locations: 1) before construction zone signs, 2) at the CMS, 3) between CMSs, and 4) at the taper. The evaluation was progressive at the beginning of the taper. (Supplemental devices were added to standard work zone traffic control devices and data was collected; then, a CMS was added to this setup and data was collected again; and finally rumble strips were added and data was collected).

The results for the northbound direction indicated that 21.9% of the vehicles were traveling in the closed lane (measured at 0.1 miles before the taper) where standard TCD was in place. This value was reduced to about 10.9% when a CMS was added. The percentage of traffic in the closed lane decreased from 11.0% when all devices were in place to 4.1% when rumble strips were added to the setup. Similar results were obtained for the southbound direction. In general, there was a reduction in speed in the closed lane, but the speed was still higher than the 55 mph speed limit.


This study evaluated the effects of two new methods to improve the roadway capacity when the middle lane of an urban freeway is closed for maintenance operations.

One traffic management plan was to shift the traffic out of the median and middle lanes and encourage drivers to use the shoulder lane and outside shoulder as the travel lanes when a shoulder existed. To accommodate work on bridges and overpasses which do not have a shoulder, the traffic was split around the middle lane and motorists were permitted to travel in the median and shoulder lanes. These two strategies were not used simultaneously. In addition to the standard work zone signs, a special sign was developed to warn the motorists about the traffic split. Only cars were encouraged to use the shoulders.

The percentage of vehicles using the shoulder was recorded at three stations located between the beginning of the lane closure and an upstream point where the first signs were put up. It was observed that at the lane closure site, where the traffic volume was high, the vehicles were slowly moving to the shoulder, whereas, at low demand conditions the traffic did not use the shoulder to the same extent. It was observed that when flow was around 2400 vph, shoulder usage increased to 38.1%, whereas at a flow level of 1600 vph, the shoulder usage was only 8.4%. Only 1.5% of the vehicles approaching the work zone changed lanes in a 300 meter
(984 ft.) section immediately upstream of the middle lane closure. Percentage of vehicles on the median lane was 56.5%, and on the shoulder lane it was 43.5%.


This report provides a brief description of 21 traffic-control strategies and devices related to traffic management, motorist information needs, traffic control services, safety hardware, and implementation for freeway work zones. They are as outlined below:

1. All lanes of freeway are closed for a short time and traffic is handled on detours.

2. Middle lane of a three-lane freeway is closed and traffic is split into both sides of the closed lane.

3. Shoulder is used as a traveled lane.

4. Active speed control (flagging, CMS, law enforcement, lane width reduction) is described. Since regulatory and advisory signs, generally, do not slow down traffic in work zones, the active speed control may be needed. A properly trained flagger "anchored" to a speed limit sign or a patrol car can reduce speed by 5 or 10 mph. A CMS reduces speed up to 5 mph. Narrow lanes slow drivers down slightly; a 9.5 ft. lane reduced speed only by 4-5 mph.

5. Entrance ramp closure.

6. Use of narrow lanes, e.g. 10 to 10.5 ft.- Lanes as narrow as 9.5 have been used on I-45 in downtown Houston. A speed reduction of up to 5 mph can be expected. However, speed variance increases in narrow lanes, and their safety impact is not known. Capacity of 1800 vph has been observed in narrow lane at long-term reconstruction sites.

7. Load zoning where large and/or heavy vehicles are prohibited from going through construction zones.

8. Use of arrow boards in lane closures and slow-moving maintenance activities.

9. Use of CMS to provide real-time warning of problems and unexpected conditions, and to advise the motorist to take proper action. Prolonged use of a CMS at the same location will reduce its effectiveness (one to two weeks are acceptable).
10. Highway Advisory Radio (HAR) is used as a tool to give the motorists information through their A.M. radios. The message length is adjusted such that drivers would receive the message at least twice while passing through the coverage area. At a reconstruction work on I-10 near Beaumont in Chamber County, Texas, HAR was used. Survey results showed that only 30% of drivers reported that they tried to tune to the HAR. 49% of drivers who did not tune to HAR said that they did not see the advance signing for HAR. Twenty percent of drivers said they were very familiar with the work zone and did not desire to tune to the HAR.

11. Special "lane-blocked" sign.

12. Special word message pavement marker to supplement MUTCD requirement may be used, e.g. exit marking, exit lane versus through lane.

13. Flagging.

14. Using law enforcement officers to do a specific traffic control function (e.g. enforcing speed limit, directing traffic). They should not be asked to merely "be present" at the work zone.

15. Portable concrete or metal roadside barriers.

16. Crash cushions mounted on shadow vehicles to shield maintenance work activity, or on a work vehicle to protect the work crew. It is also used in gore areas.

17. Temporary lighting - it should be provided when lighting of freeway is not working due to construction activity. A study in Austin on I-35 found that nighttime accidents may increase by more than 50% when urban freeway lighting is turned off.

18. Corridor management team.

19. Special traffic handling crew.

20. Advance notification.

21. Photologging or video taping of traffic control plans.


The results reported in this publication are also presented in the FHWA/RD-85/037 report by the same principal authors. The following implementation steps for work zone traffic control were

45
discussed in this publication: a) determining the need for speed reduction, b) selecting a reasonable speed, c) selecting a speed control treatment based on effectiveness, practicality and cost, and d) selecting a location for the speed control treatment implementation. Also, the advantages and disadvantages of the following four speed control approaches were tabulated: flagging, law enforcement, changeable message signs (CMS), and effective lane width reduction.

The authors pointed out that the credibility of a speed limit sign suffers when it is set unreasonably low and when no work activity is going on, but the sign is still in place. Design speed in a work zone should not be significantly lower than what a driver will reasonably expect. Suggested maximum speed reductions are:

<table>
<thead>
<tr>
<th>Roadway Type</th>
<th>Speed Reduction (mph)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural two-lane, two-way highway and urban arterial</td>
<td>10-15</td>
</tr>
<tr>
<td>Rural freeway</td>
<td>5-15</td>
</tr>
<tr>
<td>Urban freeway</td>
<td>5-10</td>
</tr>
</tbody>
</table>

The suggested speed reduction values for urban arterials is different than the values given in the FHWA report.

The authors suggested that speed control should be initiated 500 to 1000 ft. upstream of hazardous locations within the work zone. Ideally, speed control treatment should be located after the first advanced sign and in a location free of other signs. If potentially severe hazards exist, additional speed control application (e.g. another flagger, CMS) may be needed.


The report identifies several methods for slowing down traffic to acceptable speeds in work zones. The field evaluation results reported in this publication are also presented in TRR 1035 by the same authors.

From literature surveyed they identified the following speed control techniques that have been considered and/or evaluated for work zones: 1) Regulatory and advisory signing. 2) CMS. 3) Traffic activated signs. 4) Flashing lights. 5) Traffic signals and stop signs. 6) Iowa weave. 7) Colored or textured pavements. 8) Flagging and pacing. 9) Speed bumps and humps. 10) Rumble strips. 11) Transverse striping. 12) Lane width reduction. 13) Law enforcement.

A Technical Advisory Committee (TAC) developed a list of nine candidate approaches which included nine of the listed techniques. Proving ground studies were conducted on lane width reduction, transverse striping, and rumble strips. The result from proving ground studies were inconclusive. None of the three techniques
evaluated significantly reduced driver speeds. Proving ground studies were abandoned.

Field studies to evaluate short term effects of four speed control methods were carried out. The selected treatments were flagging, law enforcement, CMS, and lane width reduction. The remaining approaches (overhead flashing signals, Iowa weave section, and use of pace vehicles) were not studied.

The results from the field studies are the same as reported in the TRB 1035 by the same authors. This report also gives information on implementation of the selected speed control techniques. They suggested maximum speed reduction in the work zones by type of highway as shown below.

<table>
<thead>
<tr>
<th>Roadway type</th>
<th>Speed reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural two-lane, two-way highway</td>
<td>10-15</td>
</tr>
<tr>
<td>Rural freeway</td>
<td>5-15</td>
</tr>
<tr>
<td>Urban freeway</td>
<td>5-10</td>
</tr>
<tr>
<td>Urbana arterial</td>
<td>10-20</td>
</tr>
</tbody>
</table>

They concluded that flagging and law enforcement were the most effective methods of speed control. The innovative flagging was the most effective technique, which reduced speed on an average by 19%. The best law enforcement treatment was a uniformed police officer standing on the roadside and controlling traffic, which reduced speed by an average of 18 percent. The circulating patrol car was not very effective. The innovative flagging reduced speed 2-4 mph more than the MUTCD flagging. The flagging produced greater speed reduction at two-lane two-way rural highways, and urban arterial than urban and rural freeways. Flagging on both sides of the freeway may increase the effectiveness of it. The lane width reduction and CMS reduced speed by an average of 7%.

The authors mentioned that if unreasonably low speed limits are used, or if the reduced speed limit signs are left in place with no work activity, the credibility of the work zone speed reduction effort is generally damaged.


The authors reported results of field studies at six work sites in Texas to evaluate methods of slowing work zone traffic. The results reported in this paper are also documented in the FHWA/RD-85/037 report by the same authors. The following treatments were studied:

1. Flagging- MUTCD flagging and innovative flagging on one side or both
2. Law Enforcement- Stationary patrol car, police traffic controller, circulating patrol car, stationary patrol car
with lights on, and stationary patrol car with radar on.

2. CMS- With speed message or with speed and information message.

4. Lane width reduction- to 11.5 ft. and to 12.5 ft.

5. Rumble strip- Eight strips.

All treatments were supplemented by advisory or regulatory signs. An incomplete factorial design was used for experimental design. For data collection the treatments were in place for 1 to 2 hours, in daylight, off peak period, under free flow conditions. The vehicle speeds were collected at three stations: 1) upstream of the work zone, 2) immediately downstream from the treatment, and 3) further downstream from the treatment (near work activity). At each location, 125 samples were collected simultaneously. Only free flowing vehicles were included. Speeds were calculated from travel times over a 200 ft. "trap" section. The calculated speeds had an error of +/- 2 mph. One-way analysis of variance (ANOVA) was used for data analysis. The results for station two are shown in Figure 1.

The best treatment within each method yielded the following speed reduction:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Range</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flagging</td>
<td>8-30%</td>
<td>19%</td>
</tr>
<tr>
<td>Law enforcement</td>
<td>8-27%</td>
<td>18%</td>
</tr>
<tr>
<td>CMS</td>
<td>3-9%</td>
<td>7%</td>
</tr>
<tr>
<td>Lane reduction</td>
<td>0-16%</td>
<td>7%</td>
</tr>
</tbody>
</table>

The authors pointed out that conventional regulatory and advisory signing were ineffective in reducing speeds in work zones.


This study compared accident experience for short and long-term periods for before, during, and after freeway construction works, and evaluated adherence of TCD layout to the standards. Accident data for Chicago Area Expressway System (CAES) were obtained from IDOT. Work zone accidents were identified by matching the construction locations and activity dates to the dates on the accident records. The proposed measure of exposure was mile-days of exposure/year, which is the product of project length and project duration. With such a measure of exposure they identified four long-term and 24 intermittent/weekend (e.g. < 24 hrs) periods for analysis.

Long term sites - out of the four cases, on one construction site (resurfacing on I-55, Stevens expressway, 13 miles) there was an increase in the number of accidents during construction, but there was no increase on the other three sites. The exposure was 1372 mile-days for I-55 Expressway and 249 mile-days for the other three sites combined. Accident frequency was 1147 for I-55 and 198
Figure 1. Immediate (within 1-2 hours) speed reduction effects of selected speed control methods (From: Richards, et al, TRR 1035, 1985).

for the other three sites combined for a period of six years, of which one year was for construction period and five years for before and after construction.

Further analyses were performed for the I-55 site only. Mean accident occurrence per day was 3.0 for during and 1.694 for no-construction periods. This difference is significant. Also, the ratios of a specific category of accident to that accident for the before, during, and after period were computed and compared. Some of the findings are: accident severity decreased during construction; rear-end collision increased; ramp related accidents increased by 45%. Also, analysis of accidents when left lanes were closed vs. when right lanes were closed was performed.

Intermittent/weekend projects - Average accident rates per mile-day were 0.538, 0.78, 0.67 in before, during, and after periods, respectively. Preliminary investigation revealed a linear relationship between accident frequency and mile-day. They suggested that since ADT is approximately constant throughout before, during, and after periods, the use of mile-days as an exposure measure yielded the same results which would have been derived if vehicle-mile had been used. Accident frequency showed an increase of 0.80 accidents/mile-day. They concluded that a
fixed accident rate occurs which is independent of the length and duration of the work activity. Thus, the effect of short term construction activities depends on the accident history of the segment during non-construction periods. At low accident locations, during construction accidents may increase, and at high accident locations, during construction accidents may decrease.

For adherence check and investigation of correlation between TCD layout and speed variance at the approach, transition, and closure area, data were collected from 150 construction sites. Only 46 sites were coded for further analysis which included short and long-term, day and night projects. In general, the signs were placed closer to the taper than allowed by IDOT standards; e.g. "CONSTRUCTION AHEAD" sign was placed 1400 feet (on the average) closer to the taper. The deviation from the standard was higher in short term projects and more signs were missing. On the short term sites, an average of 2.5 missing devices were observed.

At each site visited, they measured the speed of the test car at the approach, transition, and closure area. The speed reduction between the approach and transition depended on traffic volume and number of closed lanes. Between the transition and closure area the speed did not vary considerably under light volume, but varied significantly under high volume conditions. Speed control on the approach and transition is important because the transition area, and not the closure area, governs the capacity of a work zone.

Speed profiles were developed using two video cameras— one aimed at the roadway and another at the speedometer in the car. The first important observation was that there was no speed reduction from the taper to the work area. All speed reduction was in the approach area. When only one lane was closed, the speed reduction was 5.45 mph and 7.19 mph under low and high volume conditions, respectively. When two lanes were closed, there was a speed reduction of 9.64 mph and 14.58 mph for low volume and high volume work zones, respectively. It was further observed that there was a speed recovery in high volume roads between the taper and the actual work area was 1.5 mph and 10.8 mph for single and two-lane closures, respectively. Thus, the amount of speed recovery between taper and work area depends on the amount of speed reduction in the approach area.


A part of this report discusses the use of speed bumps and undulations, and rumble strips for speed control on city streets. Speed bumps and undulations are not included in the MUTCD. The report cites British work that demonstrated that an undulation 12 feet in length and 4 inches in height did reduce speeds to 15 to 25 mph. Another installation in Toronto was successful in reducing average speed from 20-28 mph to 15-18 mph. Rumble strips have a noticeable positive effect in reducing speed in general, and in reducing accidents when placed in advance of a stop sign. The report cites an accident reduction experience at rural
intersections in Illinois with about 30% reduction in accidents. A study in Britain showed that rumble strips cause discomfort at a speed of about 25 mph. Some of the tests of rumble strips at intersections have given a speed reduction of 1-4 mph.


Portable traffic signals were installed at three work zones where traffic operation was only one-way. The signals were used in place of flaggers. All three sites were on two-lane, two-way rural highways (without a paved shoulders) in Texas. Sites 1 and 2 had repair works which lasted for only one day and at Site 3 it lasted for two days. At site 3, flaggers were used one day and the signals were used on the other day. Data collection lasted for about 4 hours at each site. Speed limit at each site was 55 mph (close to the posted speed). They also observed lack of compliance with the red signal. At Site 2, from 400 total arriving cars 2 ran in red, and at Site 3, out of 500 cars 2 ran in red light. They concluded that substantial savings in flagger labor costs could be achieved by using portable signs (for a cost of $8,000/signal and 1600 hours of useful life).


The study investigated alternatives to flaggers and ways of improving driver awareness and understanding at work zones with flaggers. Review of flagger accidents in Texas for 1983-85 indicated that 28 accidents involving a flagger were recorded; 7% of which were fatal. Drivers 70 years of age or older were involved in 38% of the flagger-related accidents for which the driver age information was available. Note that this age group represents only 5% of all licensed drivers. Poor vision and slow reaction may be the cause for these accidents.

At six work sites, TCP, flagger performance, and traffic operations were examined. The problem areas reported were: inadequate sight distance to flagger and work zone, improper advance or supplemental signing, improper flagger communication, and improper flagging procedures.

The alternatives to the use of flagger (in attention-getting capacity) were arrow boards, CMS, and flashing beacons. Alternatives to the use of flaggers to control an alternating one-way traffic were: 1) Use of "YIELD TO ONCOMING TRAFFIC" signs to self-regulate traffic operation, and 2) Portable traffic signals, a signal at each end of the work zone is placed and synchronized to operate as fixed-time signals. This can be used where a flagger would stop traffic intermittently. Cycle length is determined
based on length of work zone (e.g. for 2600 feet the cycle length is more than 4 min.). In the field evaluation of this device in a volume range of 600-10,000 vehicles, no noticeable problem was observed. Some drivers in queue entered the work zone when the light changed from green to red (sneakers).

To improve flagger safety, they suggested the use of a free standing oversized STOP/SLOW paddle, and a temporary reusable stop bar. The results were the same as reported by Booker et al. in TRB 1148. The variability of distance between the flagger and the first stopped car was reduced when the paddle or the stop bar was used.


Findings from 119 references were organized in the following areas: speed-safety relationships, factors influencing speed, speed zoning, enforcement, and speed control. A 20-page summary of these studies was provided. In the speed control section the effects of the following techniques were discussed: transverse markings, road humps, stop signs, and traffic activated signs. Note that the effects of these techniques on speed reduction were not studied for work zone traffic control.