TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/TX-81/46 +228-4		

4. Title and Subtitle	5. Report Date
Moving Maintenance Operations on Texas Urban Freeways: A Limited Overview of Current Practices and Problem Identification	January 1981
	6. Performing Organization Code

7. Author's	8. Performing Organization Report No.
Michael J. S. Faulkner and Conrad L. Dudek	Research Report 228-4

9. Performing Organization Name and Address	10. Work Unit No.
Texas Transportation Institute Texas A&M University College Station, Texas 77843	11. Contract or Grant No. Study No. 2-18-78-228
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address Texas State Department of Highways and Public Transportation -- Transportation Planning Division P. O. Box 5051 Austin, Texas 78763	Interim Report September 1977-January 1981
	14. Sponsoring Agency Code

15. Supplementary Notes
Research performed in cooperation with DOT, FHWA
Study Title: Traffic Management During Urban Freeway Maintenance Operations

16. Abstract

This report documents problem areas identified during the observation of five moving maintenance operations on urban freeways in Texas. The operations included striping and the installation of raised pavement markers. The problems were grouped into two categories; freeway design related and operational problems. The problem areas that are discussed in this report are:

Freeway design-related:

- entrance and exit ramps,
- major interchanges, and
- horizontal and vertical curvature;

Operational:

- improper use of arrowboards,
- lack of uniform procedures for freeway entry and exit,
- large spacing between caravan vehicles, and
- unnecessary lane blockage by the caravan.

Recommended solutions to the problems discussed include:

- communications,
- advance signing,
- caravan length control,
- caravan positioning procedures,
- ramp control, and
- training.

17. Key Words	18. Distribution Statement
Moving maintenance operations, work zones, traffic management, traffic control, striping, raised pavement markers, closure, ramps, interchanges.	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	37	

Form DOT F 1700.7 (8-69)

MOVING MAINTENANCE OPERATIONS ON TEXAS URBAN FREEWAYS: A LIMITED OVERVIEW OF CURRENT PRACTICES AND PROBLEM IDENTIFICATION

by

Michael J. S. Faulkner
Assistant Research Engineer

and

Conrad L. Dudek
Research Engineer

Research Report 228-4

Traffic Management During Urban Freeway
Maintenance Operations
Research Study 2-18-78-228

Sponsored by

Texas State Department of Highways and Public Transportation

In Cooperation with the

U. S. Department of Transportation
Federal Highway Administration

Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843

January 1981

CONTENTS

ACKNOWLEDGMENTS

The authors thank Mr. Bobby Hodge and Mr. Robert Jenkins (District 2), Mr. Hunter Garrison (District 12), Mr. Milton Watkins (District 18), and their staff for providing the personnel and equipment necessary to conduct this research. The assistance provided by Mr. Tom Newbern (D-18T), Contract Monitor, is also greatly appreciated.

Study 228 research was conducted with the guidance of a Technical Advisory Committee:

W. R. Brown, Supervising Maintenance Engineer, D-18M
Walter Collier, District Maintenance Engineer, District 15
Billie E. Davis, District Maintenance Engineer, District 2
Milton Dietert, Senior Traffic Engineer, District 15
Larry Galloway, Engineer Technician IV, District 12
Hunter Garrison, District Maintenance Engineer, District 12
Henry Grann, Supervising Traffic Engineer, District 18
Herman Haenel, Supervising Traffic Engineer, D-18T
Bobby Hodge, Supervising Traffic Engineer, District 2
Tom Newbern, Traffic Engineer, D-18T
Russell G. Taylor, Engineering Technician V, District 14
Milton Watkins, District Maintenance Engineer, District 18
John Wilder, District Maintenance Engineer, District 14

The contributions of the Committee members are gratefully acknowledged.

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 Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

I. INTRODUCTION

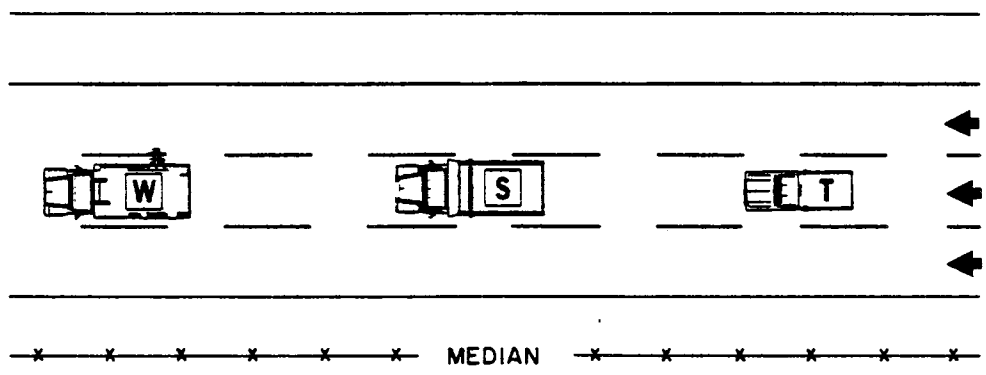
Moving maintenance operations include activities such as installing raised pavement markers, striping, sweeping, etc. A Technical Advisory Committee (1) made up of Texas State Department of Highways and Public Transportation Maintenance and Traffic Engineers identified moving maintenance operations on urban freeways as one of the most critical work zone problems. This report introduces terminology used in moving maintenance operations and defines its purpose. The study and the safety problems observed during the field investigations of several operations are discussed. Recommendations developed as a result of these observations are included.

Terminology

Moving maintenance is usually conducted by personnel using a series of vehicles called a *caravan*, each vehicle in this caravan having a specific purpose. Some vehicles are used in the application of paint, thermo-plastic or pavement markers. (Sweeping operations and herbicide spraying generally do not involve lane closures and therefore were not included in this study.) Others carry additional supplies for the maintenance operation, protect the vehicle performing the maintenance, and provide sight distance to approaching motorists (Figure 1 represents a typical caravan). Each of the caravans observed included from three to five vehicles.

Purpose

The purpose of a moving maintenance caravan is to provide worker and motorist safety, and dry time (i.e., time for paint, thermoplastic, or epoxy to dry).



VEHICLE W - *Work Vehicle*, Responsible for placing stripes or pavement markers. (During striping operations - referred to as a *Striper*.)

VEHICLE S - *Shadow Vehicle*, Responsible for providing supplies and protecting Vehicle W. (Not always required.)

VEHICLE T - *Trail Vehicle (last caravan)*, Responsible for protecting Vehicles W and S and providing sufficient sight distance to approaching motorists to allow a safe exit from the lane occupied by the caravan.

Figure 1. A Typical Moving Maintenance Caravan

Worker Safety

In the maintenance operations observed, three methods of providing worker safety (traffic control) were observed. One method utilized standard lane closures (one or two lane closures) during the installation of raised pavement markers. Another marker operation used a moving caravan with cones closing the blocked lane between caravan vehicles. The third method consisted of only a moving caravan. Figure 2 illustrates each of the methods observed.

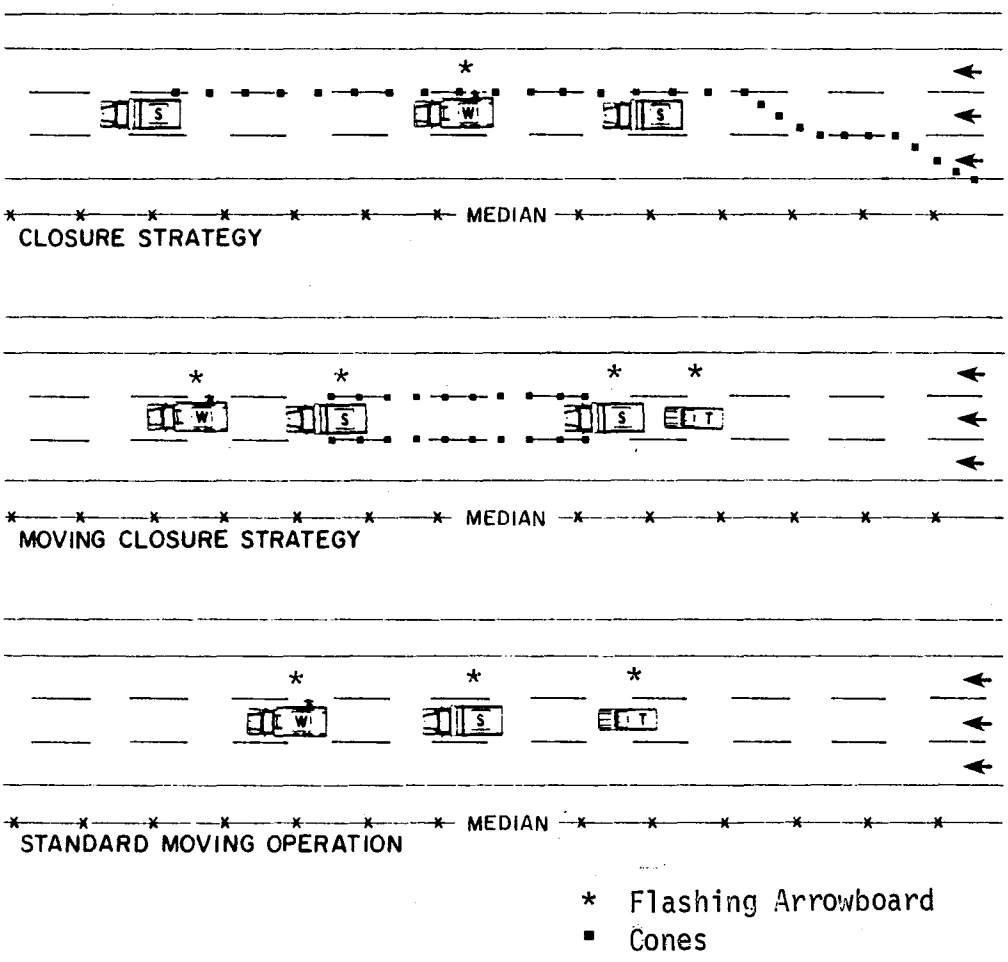


Figure 2. Three Moving Maintenance Strategies

Motorist Safety

Flashing or sequencing arrowboards have become the primary device used in increasing the visibility of maintenance vehicles, thus improving motorist safety. Flashing lights, rotating beacons, flags and signs should also be used on maintenance vehicles to increase visibility (2).

During the field observations, two of the operations supplemented the arrowboards and other devices with innovative advance signing. This advance signing was accomplished with the use of a static sign mounted on a vehicle which trailed the caravan on the shoulder.

Dry Time

Finally, a moving maintenance caravan provides sufficient dry time (the time required for the paint, thermo-plastic, or marker epoxy to dry) so that vehicles crossing the stripe or pavement marker will not track paint across the lane or displace markers from their intended location. The caravan must therefore perform as a single unit to provide the needed dry time without allowing traffic to cross through the caravan.

II. STUDY DESCRIPTION

The research conducted in the study documented the performance of moving maintenance operations on urban freeways in Texas, and identified the weaknesses or hazards of the operations.

Five moving maintenance operations involving striping and marker installation were observed by a TTI research team in three major metropolitan cities--Dallas, Fort Worth, and Houston, Texas. The operations, performed by the Texas State Department of Highways and Public Transportation (SDHPT) and private contractors, include:

1. two paint-striping operations by the SDHPT,
2. one thermo-plastic striping project by a contractor, and
3. two raised pavement marker installations by a contractor.

A ½-inch color video tape recording system and a 35mm camera were used for data collection. The video tape provided a visual record for detailed study of the maintenance operations, the equipment used, and the effect on traffic flow. The 35mm slides and photographs provided a detailed record of equipment and vehicles used in the operations. Data were collected from a bucket truck, vehicle roof-top, in-stream moving vehicle, and a high-rise building roof-top.

In some of the later studies, two vehicles were used to collect data in addition to the film documentation. Each vehicle was equipped with a two-way radio and distance measuring instrument (DMI). The first vehicle was positioned in the maintenance caravan to measure caravan travel times, traffic volumes, lane distributions, and delays (time periods during which the caravan was stopped). The second vehicle was driven past the caravan several times.

During these passes of the caravan, sight distances to the caravan, caravan vehicle spacings, and total caravan length were recorded. This information, when coupled with the video data, helped define some of the safety problems associated with moving maintenance operations.

III. SAFETY PROBLEMS

The safety problems identified as a result of the observations are grouped into two categories. The first category is freeway design related. These problems result from the geometric design of the roadway. The second category is operational related. These problems are a result of the manner in which the maintenance is performed. Discussion of specific problems in each category follow.

FREEWAY DESIGN RELATED PROBLEMS

Freeway design elements that contribute to potential safety problems during moving maintenance operations are:

- entrance and exit ramps
- major interchanges (freeway-to-freeway), and
- horizontal and vertical curvature.

The types of problems that occur are influenced by the lane occupied by the maintenance caravan.

Entrance and Exit Ramps

The observed problems associated with entrance and exit ramps occur when the maintenance caravan is on the shoulder or middle lanes. Generally, ramp related problems do not occur when the caravan is on the median lane unless there are left-hand entrances and exits.

Shoulder Lane at Entrance Ramps

Ramp drivers crossing through the caravan create the major problem when a caravan is on the shoulder lane at an entrance ramp. This type of maneuver is contrary to one of the primary purposes of a caravan.

It is not surprising that most drivers cross through caravans at entrance ramps. Drivers are not advised by signs, traffic laws, or in driver's training that they cannot; nor are they able to determine exactly where the caravan begins or ends. They must also be concerned with other drivers on the ramp. Some ramp drivers cross directly through the caravan and merge into the adjacent lanes, thus creating a safety hazard when visibility is obstructed by maintenance vehicles. Other drivers merge into the caravan before moving to the adjacent lane.

Of additional concern is the safety hazard created by the indecision of the ramp driver on entering the freeway. In the studies conducted, many ramp drivers were observed rapidly accelerating to merge in front of the caravan. Several of these drivers drove on the shoulder before merging. Other drivers either accelerated or decelerated on the ramp and/or acceleration lane and merged between two caravan vehicles.

The driver who merges between caravan vehicles creates two problems. First, because he has merged with the caravan, his vehicle speed is equal to that of the caravan (5-10 mph). When he merges into an open lane he is forced to accelerate very rapidly to the higher freeway speeds. Secondly, the larger caravan vehicles may obstruct the visibility of the approaching drivers. Therefore when the trapped drivers merge to the open lane, approaching drivers may be forced into making an erratic maneuver or abruptly decelerate.

Shoulder Lane Near and At Exit Ramps

There is considerable indecision on the part of an exiting driver when he becomes trapped behind a caravan upstream from, but near, the desired exit ramp. The driver must decide whether to remain behind the slow moving caravan or to merge into the adjacent lane, accelerate, and try to beat the caravan to the ramp. When the latter choice is made, many drivers are forced to cross the caravan because the caravan arrives at the ramp before they do.

Middle Lanes

Indecision and the failure to arrive at an exit ramp before the caravan are also critical problems when maintenance is being performed on one of the middle lanes. Drivers approaching a caravan must decide very quickly whether to merge right or left. If a driver merges left, he must then pass the caravan and then move to the right across at least two lanes to the exit. If the driver, however, is unable to pass the caravan he is forced to either miss the exit or merge with the caravan and then cross over to make the exit.

Current information provided drivers during moving maintenance operations is inadequate for them to make timely and appropriate decisions. A driver approaching a slow moving maintenance vehicle does not know if other maintenance vehicles are ahead, nor is the length of the caravan known.

Recommendations

Problems created by entrance and exit ramps can be alleviated with ramp control, advance signing and/or better control of the caravan length. When the shoulder lane is blocked at entrance ramps, entering traffic can be controlled through the use of a ramp control vehicle. This vehicle would block the ramp either at the frontage road or at the entrance to the main lanes.

The use of advance signing and control of the caravan length (vehicle spacing) should reduce the confusion and indecision of motorists near exit ramps, or when the caravan is blocking one of the middle lanes upstream from an exit. The advance signing should provide advance warning concerning the blocked lane, while controlling the caravan length may reduce the number of crossing violations with the caravan. A controlled caravan length should also aid the motorist in determining the total caravan length in relation to the desired downstream exit.

Ramp control, advance signing and controlled caravan length are discussed in more detail in Chapter IV.

Major Interchanges

The problems observed at freeway-to-freeway interchanges generally were observed to occur when the caravan was near the exit ramp connectors or the entrance ramps from the crossing freeway.

Exit Ramp Connectors

Lane drops create the major problem at the exit ramp connector. Specifically, the problem occurs when maintenance is being performed upstream from the interchange on a middle lane that suddenly becomes the shoulder lane through the interchange because of a lane drop to the crossing freeway (see Figure 3). In the maintenance operations observed, the trailing vehicle in the caravan normally displayed a double-headed flashing arrow encouraging drivers to pass the caravan on either side. As the caravan approached the interchange, the double-headed arrow presented erroneous information to through drivers. They were incorrectly instructed to pass on the right side of the caravan. Drivers electing to do so, were suddenly found on the ramp leading to the crossing freeway.

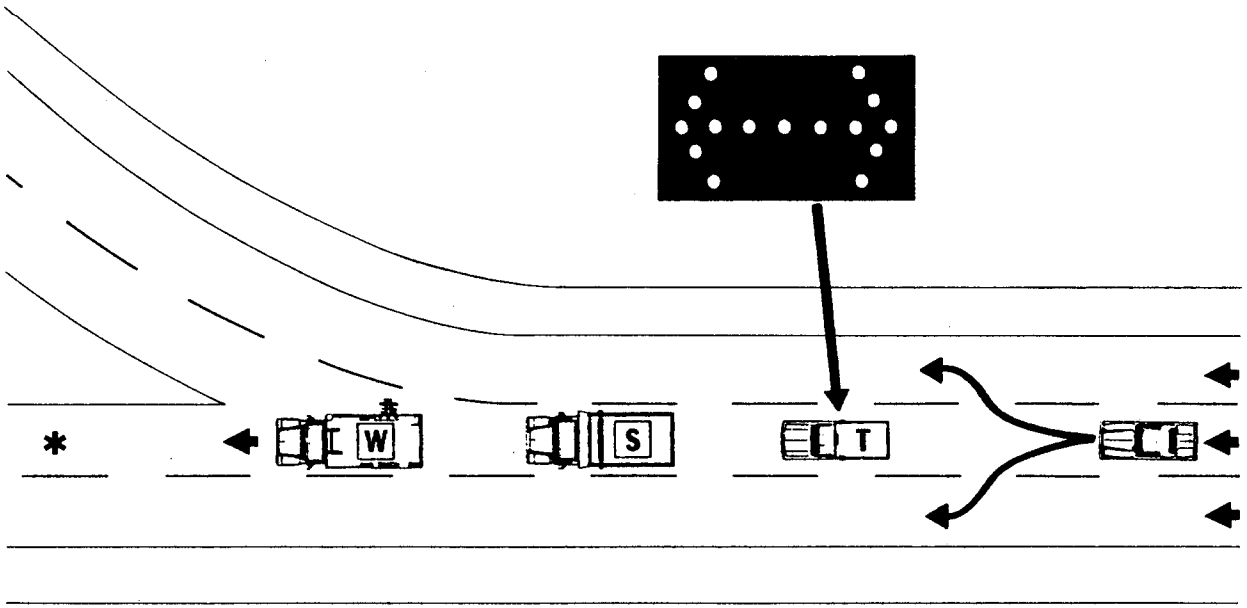


Figure 3. Freeway Design Related Problem at Major Freeway Interchange

Another problem that occurs when a moving maintenance caravan approaches a major interchange is when it occupies a lane assigned by overhead signs to a specific route. Drivers become confused and have difficulty in identifying the proper lane they should be in for the desired routing.

Entrance Ramp Connectors

When the caravan passes through the interchange and approaches the entrance ramp connector from the crossing freeway, problems similar to those of local entrance ramps occur. These problems, however, are amplified because of heavier volumes, higher speeds, and sometimes reduced sight distances due to grade separations (overpasses and underpasses).

Recommendations

Specialized interchange signing and ramp control can reduce problems encountered while performing moving maintenance at major interchanges.

Ramp control on entrance ramp connectors is different from that used on local entrance ramps. The optional vehicle is used on the connector as a means of providing advance warning, not closure.

Specialized interchange signing and ramp control are discussed in more detail in Chapter IV.

Horizontal and Vertical Curvature

Horizontal Curvature

Figure 4 illustrates a moving maintenance caravan on a horizontal curve. As the trailing vehicle travels along the curve, it becomes increasingly difficult for drivers approaching on the tangent to perceive which lane is blocked. They must wait until they get closer to the caravan to fully recognize which lane is blocked before they can merge left or right. Depending on the length

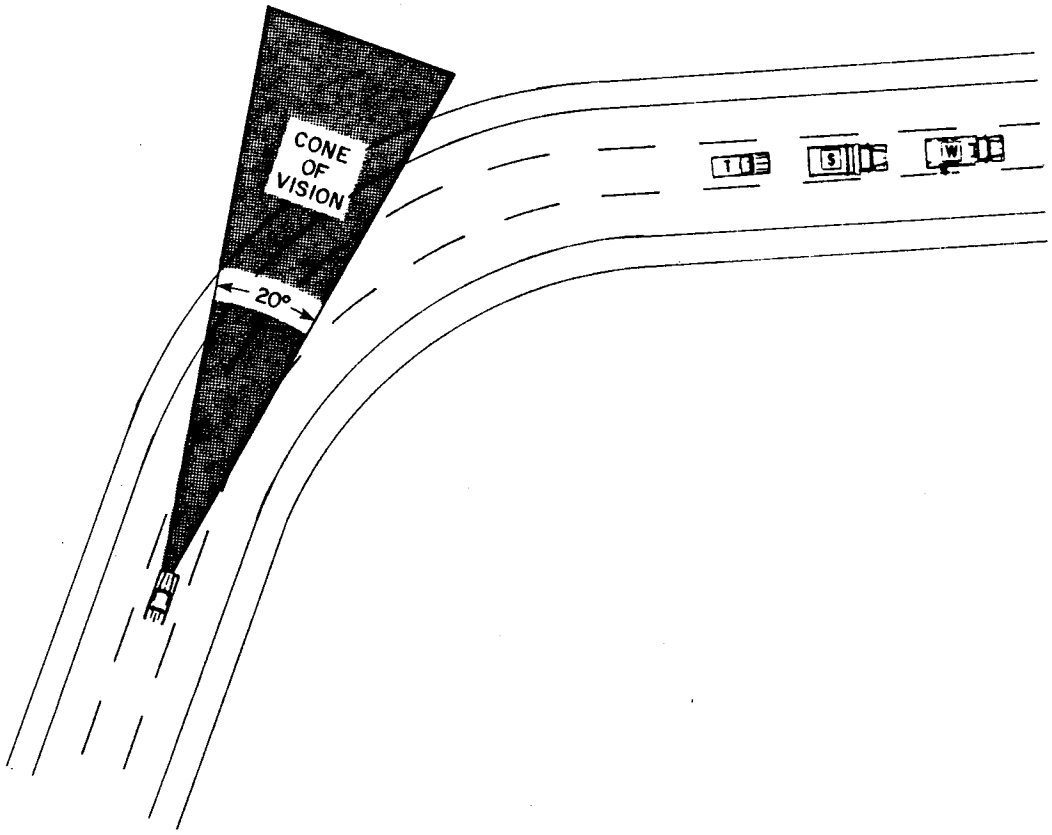


Figure 4. Freeway Design Related Problem at Horizontal Curve

and degree of curve, sufficient sight distance is often not available for proper lane changing. Drivers then become trapped behind the caravan and must merge at greatly reduced speeds.

Vertical Curvature

The problem associated with vertical curvature is one of providing adequate driver sight distance to the maintenance caravan. When the trailing vehicle is on the crest or just upstream from the crest, it usually provides adequate sight distance to allow drivers sufficient time to change lanes. When the trailing vehicle fails to provide adequate sight distance, drivers approaching the unexpected lane closure at high speeds must brake rapidly and become trapped in the closed lane.

In two of the operations studied, one dilemma occurred when the trail vehicle stopped to provide sight distance. As the remainder of the caravan moved downstream, a large gap occurred between the trail vehicle and the rest of the caravan. Several passing motorists were observed merging into the caravan and crossing into the adjacent lane. This maneuver is not desirable because it promotes vehicles crossing through the caravan.

Recommendations

Problems associated with horizontal and vertical curvature can be reduced through advance signing and by controlling caravan length. Advance signing would help drivers identify the blocked lane. Maintaining a controlled length can be accomplished in two ways. The first method requires that the caravan retain uniform vehicle spacing and travel at its normal speed. In the second method, the trail vehicle stops at a point in the curve where there is sufficient sight distance for approaching motorists to leave the blocked lane. The

trail vehicle remains stopped until the leading portion of the caravan clears the curve. When sufficient sight distance is available the trail vehicle should move to its normal spacing.

Advance signing and controlled caravan length are discussed in greater detail in Chapter IV.

OPERATIONAL PROBLEMS

The second category of problems is termed "operational" because they are related to the manner in which the moving maintenance is performed. Operational problems observed include:

- improper use of arrowboards,
- lack of uniform procedures for freeway entry and exit,
- large spacing between caravan vehicles, and
- unnecessary lane blockage by the caravan.

These problems can be alleviated through the development of improved guidelines and uniform procedures.

Improper Use of Arrowboards

Generally the only signs used during a moving maintenance operation are mounted on the caravan vehicles. Flashing arrowboards have recently become the primary signs for the trailing vehicles on urban freeways because of their high target value and legibility distance.

The problems observed were ones of misuse or over use. When the maintenance caravan was off the roadway or not performing the maintenance, the arrowboard remained in operation. Thus incorrect information was displayed to approaching motorists.

The arrowboard was again improperly used when the caravan entered the freeway. The arrowboard display which was to be used while performing the maintenance was used in completing the entry to the freeway. This display did not always relate the proper information to approaching motorists. The same improper usage occurred during the caravan's exit from the freeway.

Recommendations

This problem can be easily eliminated. As the caravan is moving into position, the arrowboard should be on and remain in the "caution" display until the entire caravan reaches the desired lane. The arrowboard should then be switched to the desired display. This display should then be used until the maintenance is completed in that lane. The "caution" display should then be visible to the motorist when the caravan is exiting the freeway. If the maintenance vehicles need to travel as a caravan at speeds less than the traffic stream after exiting the freeway, the "caution" display should continue to be visible.

The arrowboard should be turned off when the caravan is stopped off the roadway or when it is no longer important for the vehicles to travel as a caravan (e.g., while moving from the yards to the maintenance site or from one site to another). When the caravan vehicles are stopped off the roadway and the rotating beacons and/or flashing lights are needed for safety, the arrowboard with the "caution" display could be used.

Note: the controls on most vehicles for the arrowboard are mounted outside the truck. Placement of these controls inside the truck cab would allow the displayed message (arrow, chevron, etc.) to be changed as needed.

Lack of Uniform Procedures for Freeway Entry and Exit

The movement of the caravan onto or off of the freeway can have a major impact on the operation of the facility in terms of roadway capacity, flow, speeds, lane changes, and driver confusion. The entry and exit procedures were different for each maintenance activity observed, indicating a lack of uniform procedure. Although the first caravan vehicle would lead the caravan onto and off of the freeway, there were no established patterns for the other following vehicles. The procedures varied from a situation where the vehicles moved as a caravan from lane to lane to where each caravan vehicle seemed to move independently. Several freeway lanes can become affected as a result of this independent movement.

Recommendations

The developments of uniform procedures is required to eliminate the problems observed during caravan entry and exit onto and off of the freeway. The suggested procedures are discussed in detail in Chapter IV.

Large Spacing Between Caravan Vehicles

The merging of passing vehicles with the caravan and the crossing of passing motorists between caravan vehicles can result from excessive vehicle spacing. The merging and crossing of these motorists violates one of the primary purposes of the caravans. At one location all 14 observed exiting vehicles crossed between caravan vehicles or passed the trail on the right while the caravan blocked the exit. This movement was observed most often as the caravan approached an exit ramp or blocked an entrance ramp. However, similar movements were observed at major interchange connectors. The problems associated with these movements have been discussed in more detail in previous sections.

Recommendations

The problems resulting from large vehicle spacings can be reduced through the development of guidelines. The guidelines on caravan vehicle spacing and total caravan length are relative to the maintenance operation being performed and the number of vehicles in the caravan. If vehicle spacing becomes excessive, the caravan should be defined through the use of cones.

The guidelines for controlled caravan length are discussed in Chapter IV.

Unnecessary Lane Blockage by the Caravan

Poor planning resulted in prolonged and thus unnecessary lane closures during some of the observed maintenance operations. The duration of some of the lane closures was prolonged because sufficient supplies (e.g., paint, pavement markers, or epoxy) were not available on the applicator machine. The work stoppage observed ranged from momentary to more than one hour. These work delays extend the time that the lane is closed to traffic.

Supplies were normally kept on one of the vehicles in the caravan; thus, workers were forced to walk adjacent to fast moving traffic to carry the supplies to the applicator vehicle.

Recommendations

Unnecessary lane blockage can be eliminated with proper planning. Planning is accomplished through the division of the project length into sections. These sections should be no longer than the capabilities of the loaded striper or epoxy applicator. The division of project length will allow the striper or applicator to be filled while the caravan is out of the main lanes and off of the roadway.

IV. RECOMMENDATIONS

The information discussed in this chapter summarizes the observations made during four weeks of studying moving maintenance operations. Some of the recommendations are suggested improvements to procedures being used in only a portion of the operations observed. Others were developed based on engineering judgment. These recommendations should be tested in the field to assess their relative effectiveness.

Communications

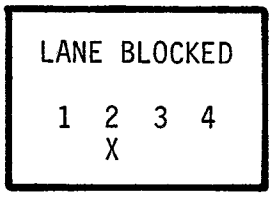
A working communications system between vehicles in a moving maintenance caravan is an essential element in reducing almost all operational related problems. This system should be made up of either two-way or citizen band radios, however, other systems could be developed. Of the moving maintenance operations observed (not including the multi-lane closure study), only those operations performed by the contractors had complete communications between all vehicles. State performed operations had only limited communication, generally between striper and crew supervisor. In the activity that used a multi-lane closure, no communications were available between any of the contractors' vehicles. Vehicle communications could have been useful in positioning the caravan vehicles, to eliminate improper arrowboard display, and in communicating caravan location to the ramp control vehicle.

Advance Signing (Entrance and Exit Ramps, Horizontal and Vertical Curvature)

The advance signing used in normal work zone applications does not meet the needs of moving maintenance operations. Specialized signing is needed to eliminate the problems associated with entrance and exit ramps and horizontal

and vertical curvature. Of the operations observed, only two used any advance signing (Figure 5). In both cases, vehicle-mounted warning signs and arrowboards were used upstream from the caravan to warn approaching motorists of the operation.

The signing, however, failed to identify the blocked lane. Through the application of previous study results (3), the lane occupied by the moving maintenance caravan could be identified. This can be accomplished with either a black legend on orange background static sign or a changeable message sign with a message similar to the following:



Although the above message would be that used on an eight lane freeway having four lanes per direction; it is recommended that this type sign be field-tested on urban freeways having three lanes or more per direction. The sign can be mounted on a vehicle which should be located upstream from the last caravan (trail) vehicle. A distance of at least 1000 ft. will assure minimum maneuvering room and sight distance to the caravan, and should reduce the amount of vehicle trapping. Where possible, the advance signing vehicle should be located on the shoulder relative to the location of the blocked lane.

On four lane freeways having two lanes for each direction, a flashing arrowboard should provide sufficient advance warning.

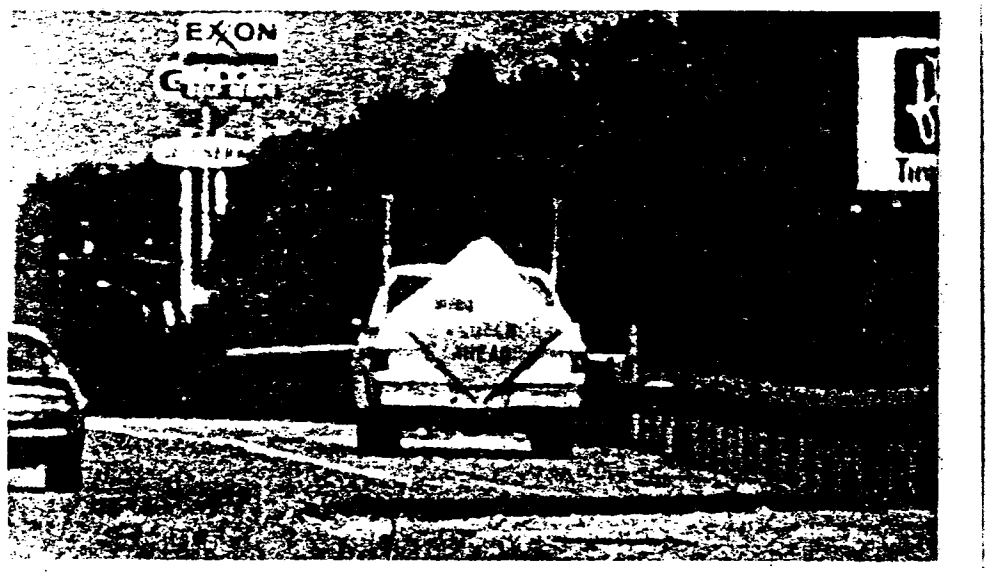


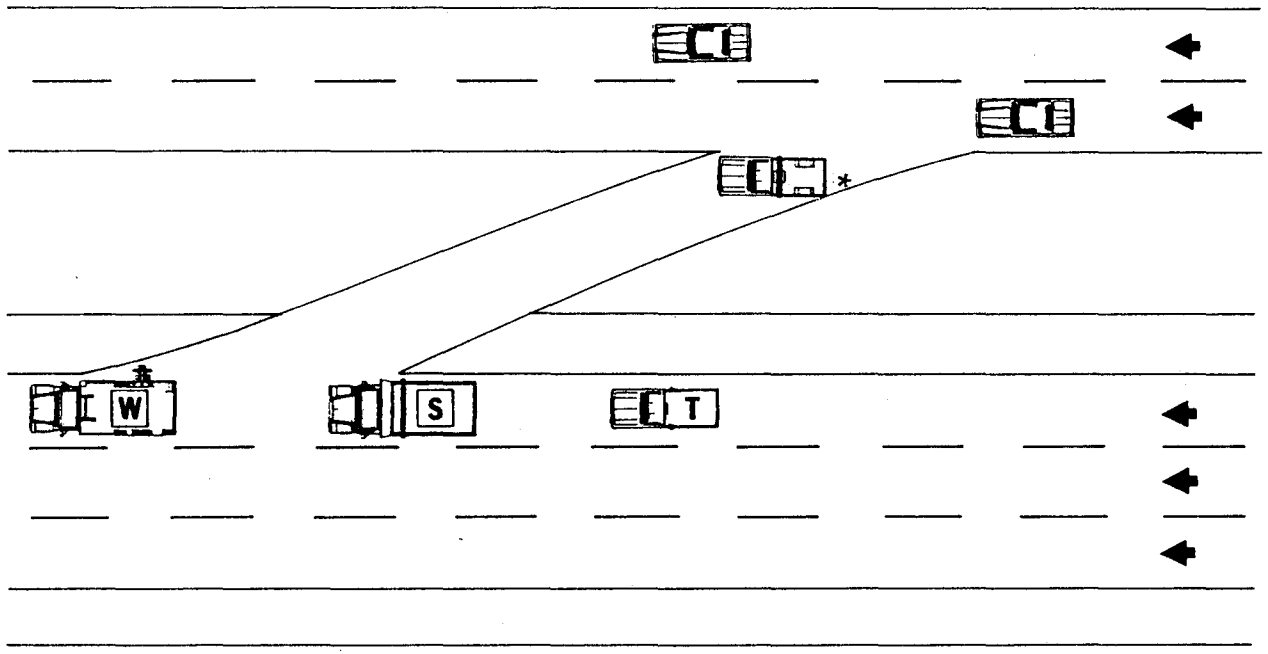
Figure 5. Advance Signing for Moving Maintenance.

Ramp Control (Entrance Ramp, Major Interchange and Connectors)

If the operation approaches and passes local street entrance ramps in the shoulder lane, the crossing of entering vehicles between caravan vehicles can become a motorist hazard. Crossing traffic can be controlled through the use of a ramp control vehicle. The operator of this vehicle, however, must be familiar with the roadway geometrics in order to effectively complete the control. The procedure could be as follows:

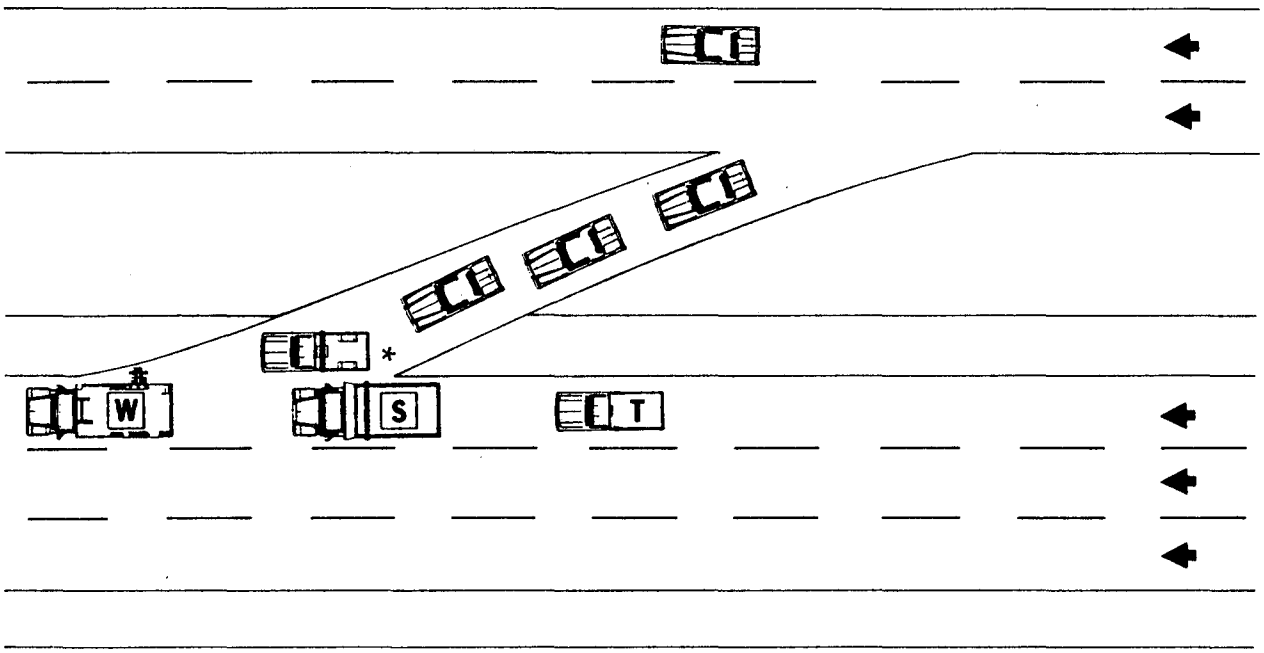
> If the frontage road is *continuous* with additional downstream ramps, the ramp is blocked at the frontage road entrance and traffic is directed to the next entrance ramp (see Figure 6). If the frontage road is *discontinuous*, the ramp should be blocked at the ramp entrance to the main lanes. This will provide some storage in an attempt to have minimal impact on the frontage road operation (see Figure 7). Vehicle communication should be maintained to ensure that successive entrance ramps are not blocked.

If the operation approaches and passes a freeway-to-freeway interchange, a procedure similar to that used for a local street ramp with a continuous frontage road should be used with ramp blockage exception. The ramp control vehicles would be used as a warning vehicle to provide adequate information to the entering motorist in order to reduce confusion and merge speeds. In this situation, the ramp control vehicle performs a function similar to the advance warning vehicle.



*Ramp Control

Figure 6. Ramp Control with Continuous Frontage Roads



*Ramp Control

Figure 7. Ramp Control with Discontinuous Frontage Roads

Caravan Positioning Procedures (Caravan Entry and Exit)

The movement of the caravan onto or off of the freeway should be a coordinated effort with the trail vehicle providing coordination. The *movement onto the freeway* should follow a procedure similar to the following:

> The caravan, in entering the freeway, should maintain a close vehicle spacing (approximately 20 ft. between vehicles) with the vehicles arranged in the proper order from ramp controller to trail vehicle. The initial movement of the caravan should be coordinated between vehicles and the arrowboards put into operation at this time (caution display). After all vehicles are on the shoulder and attain an equal speed, movement onto the roadway should be begun with the trail vehicle making the first movement. The remaining vehicles should then complete a "last-to-first" movement until all caravan vehicles have completed the entry from trail vehicle to applicator vehicle. Radio communication should be maintained to assure that a one-lane move is completed before the movement to another lane is begun. The procedure is repeated until the desired lane is reached. The proper arrowboard display should then be initiated.

The *movement off of the roadway* is similar to that of the caravan entry. The exiting procedure should be similar to the following:

> As the operation in the occupied lane is completed, the caravan vehicles should move into a close vehicle spacing (approximately 20 ft. between vehicles). This close spacing

is begun as each vehicle passes the end of the project section. Once the trail vehicle leaves the section and the close spacing is completed, the caravan is prepared to begin the lane change. The lane change is initiated from the trail vehicle and a "last-to-first" movement is continued until all vehicles have completed the movement. This procedure is continued until the desired lane is reached. During the exiting procedure the arrowboard should show a "caution" indication. If leaving the roadway, the arrowboard should be turned off when the caravan reaches a full stop, or leaves the roadway.

Radio communication is important to assure that the proper arrowboard display is used and that only a one-lane maneuver is performed at a time.

Caravan Length Control (Entrance and Exit Ramps, Major Interchange, Horizontal and Vertical Curvature)

The control of moving maintenance caravan length is essential in reducing problems associated with entrance and exit ramps, major interchanges, and horizontal and vertical curvature. In reducing the problems at ramps and interchanges, a minimum caravan length is required. Caravan speed and paint, thermoplastic, or epoxy dry time are the controlling factors in determinimg caravan length. Their relationship can be used in the following equation:

$$L = 1.47\ vt$$

Where L = caravan length (ft.)
v = speed (mph)
t = dry time (sec.)

$$\text{vehicle spacing} = \frac{L}{n-1}$$

Where L = caravan length
n = number of vehicles in caravan

For example, the minimum dry time for a quick drying paint is 30 seconds. The average caravan speed for this operation is 10 mph and three vehicles are used in the caravan (see Figure 8). Therefore,

$$L = 1.47\ (10\ \text{mph})(30\ \text{sec}) = 441\ \text{ft.}$$
Round off to 450 ft.

$$\text{Vehicle spacing} = \frac{450}{3-1} = 225\ \text{ft.}$$

For a raised pavement marker operation, the minimum set time for a type I-M epoxy is 40 minutes. Assuming an application speed of 2 mph, the maximum caravan length is 1.5 miles (7920 feet).

$$1.47\ (2\ \text{mph})(2400\ \text{sec.}) = 7056\ \text{ft. or } 1.34\ \text{miles}$$
Round off to 1.5 miles

The determination of vehicle spacings in this operation is not similar to striping. From observations made during one raised pavement marker operation, minimum caravan length was accomplished by grouping two vehicles at each end of the caravan. This, however, resulted in an excessive gap between groups. The caravan was defined through the use of cones and the integrity of the caravan was not penetrated by crossing vehicles. The arrangement of vehicles used in this operation is illustrated in Figure 9.

In determining the minimum caravan length and vehicle spacings, the advance signing and ramp control vehicles were not included, since these vehicles are not in the main lane traffic flow as is the caravan. It is highly recommended that one advance signing vehicle and one ramp control vehicle be included in the moving maintenance operation to supplement the caravan when the caravan is likely to face the problems discussed earlier (and listed on pages 20 and 23). The ramp control vehicle could be the lead vehicle when not at a ramp location.

The control of caravan length in reducing problems associated with sight distances resulting from horizontal and vertical curvature has two possible

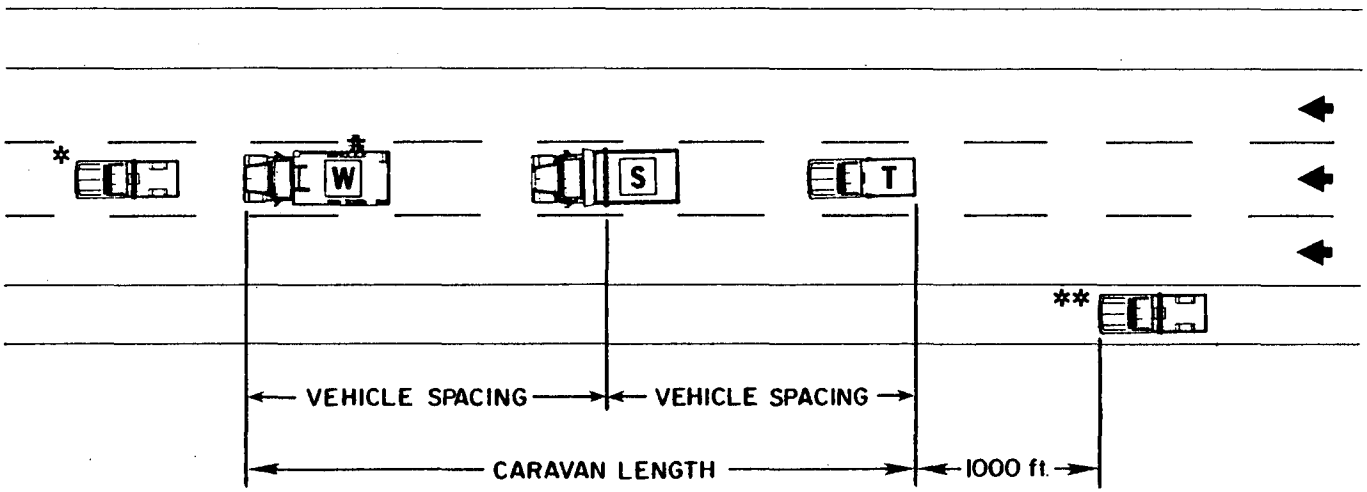


Figure 8. Moving Maintenance Caravan with Three Caravan Vehicles and Short Paint Dry Time

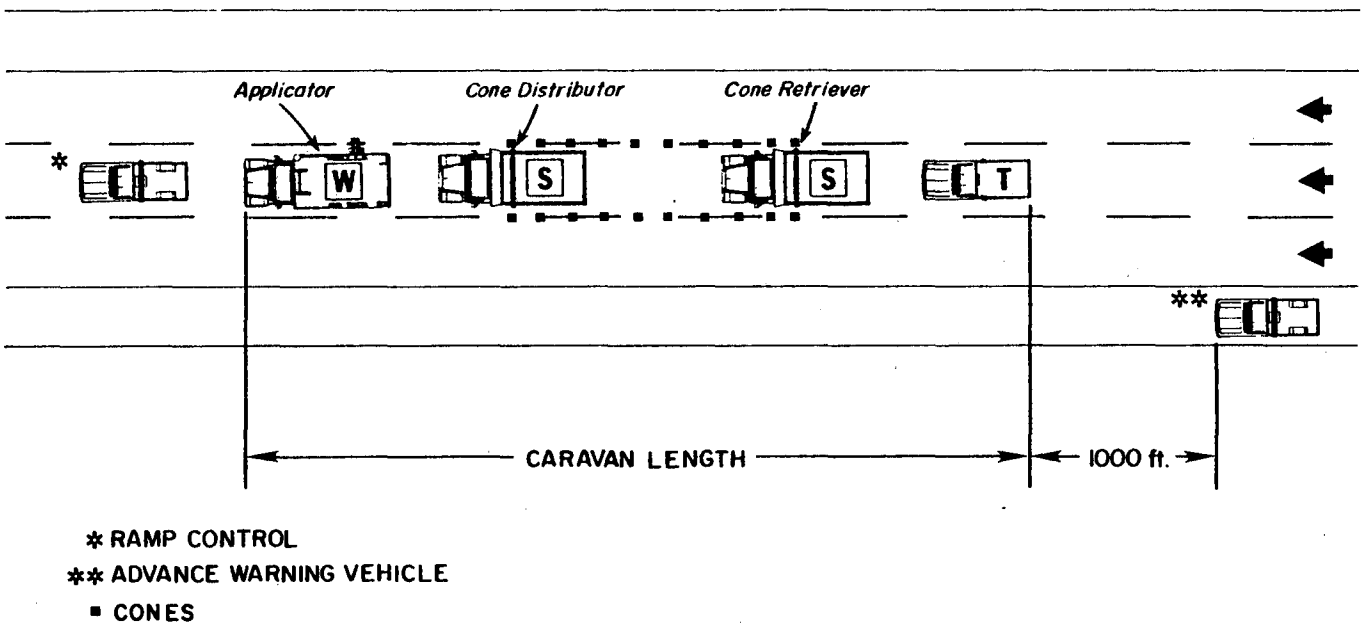


Figure 9. Moving Maintenance Caravan with Four Caravan Vehicles and Long Epoxy Dry Time

options. First, normal minimum length and operations can be followed. In this method, it is assumed that the advance signing vehicle provide the information and sight distance required for a safe operation.

The second method of length control requires that the trail vehicle and the advance warning vehicle stop for short periods of time. This stoppage would occur at some point in the curve where sufficient sight distance would be provided for approaching motorists. These vehicles would remain stopped until the caravan had moved downstream far enough to supply the needed 1500 ft. for sight distance in addition to the normal vehicle spacing (4). This distance is consistent with other research recommendations. For example, if normal spacing between the trail and the next caravan vehicle was 250 feet, the trail vehicle would remain stopped until a separation of 1250 feet (1000 ft. + 250 ft.) resulted. This distance separation could be performed easily by counting the lane lines (e.g., 10 ft. stripe + 30 ft. gap = 40 ft.; therefore, 1250 ft. = 31 stripes).

Additional research is required to determine the total effectiveness of the advance signing relative to sight distance and geometrics (horizontal and vertical curvature). Should the advance signing prove effective, the increased separation and stoppage of the trail vehicle in the main lane may not be necessary.

Specialized Interchange Signing (Major Interchanges)

Specialized signing is needed to provide approaching motorists with information concerning the proper lane designations for access to crossing freeways. The signing presently used is insufficient. Additional research, however, is required to acheive a solution to this problem area. Changeable message signs could be helpful in solving this problem.

Training

Safety meetings, short courses, and training have been utilized in an attempt to provide safer conditions for both the workers and the motorists. However, there has been no specialized training or guidance for those crews responsible for the completion of moving maintenance operations. These individuals learn their procedures from field experience and from the knowledge of others. Because of this educational process, each District has its individual maintenance procedures. These District differences include procedures, equipment used (type and amount), and products used.

A specialized training program for those individuals involved with moving operations has been developed and if utilized would provide a basis for uniform operation across the State. These standards would in turn provide guidelines for contractors and thus maintain a uniformity in operations. Such training includes caravan entry and exiting procedures, a basic knowledge of sight distance, vehicle spacing and caravan length, equipment operation and message understanding (arrowpanels, changeable message signs, etc.), traffic control device placement and retrieval and flagging procedures.

REFERENCES

1. Study 228 Technical Advisory Committee Minutes. December 14, 1977.

2. "Texas Manual on Uniform Traffic Control Devices." State Department of Highways and Public Transportation, Austin, Texas. 1980.

3. C. L. Dudek, et al. "Human Factors for Real-Time Motorist Information Displays, Volume I - Design Guide." Texas Transportation Institute, Research Report FHWA-RD-78-5. September 1978.

4. J. L. Graham, D. J. Migletz, and J. C. Glennon. "Guidelines for the Application of Arrowboards in Work Zones." Midwest Research Institute, Report No. FHWA-RD-79-58. December 1978.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F