Field Evaluation of Moving Maintenance Operations on Texas Urban Freeways

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Problem areas identified during the observation of five moving maintenance operations on Texas urban freeways are discussed. The operations included striping and the installation of raised pavement markers. The identified problem areas were grouped into two categories: problems related to freeway design and operational problems. Problems related to freeway design occur at entrance and exit ramps and major interchanges or result from horizontal and vertical curvature. Operational problems include the improper use of arrowboards, the lack of uniform procedures for freeway entry and exit, large spacings between caravan vehicles, and unnecessary lane blockage by the caravan. The recommended solutions to the problems are improved communications, effective advance signing, controlled caravan length, caravan positioning procedures observed during certain operations, and modifications to procedures observed in others.

This paper identifies and discusses safety problems observed during field investigations of several moving maintenance operations. Terminology used in moving maintenance operations is introduced, and its purpose is defined. Recommendations developed as a result of these observations are included.

TERMINOLOGY

Moving maintenance is usually conducted by using a series of vehicles called a caravan. Each vehicle in a caravan has a specific purpose. Some are used in the application of paint, thermoplastic, 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.

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) while a maintenance activity is performed. A brief discussion of each purpose follows.

Worker Safety

Three methods of providing worker safety (traffic control) were observed in the study. One method used standard lane closures (one- or two-lane closures) during the installation of raised pavement markers. Another marker operation used a moving caravan and cones to close the blocked lane between caravan vehicles. The third method was a typical caravan.

Motorist Safety

Flashing or sequencing arrowboards have become the primary device used to increase the visibility of maintenance vehicles and thus improve motorist safety. Flashing lights, rotating beacons, flags, and signs were also observed on maintenance vehicles to increase visibility.

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

Dry Time

Finally, a moving maintenance caravan provides sufficient dry time 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 and traffic must not be allowed to penetrate or cross through it.

STUDY DESCRIPTION

The research conducted in the study documented the performance of moving maintenance operations on urban freeways in Texas and identified weaknesses or hazards observed during the operations. Moving maintenance operations were observed by a Texas Transportation Institute (TTI) research team in three major metropolitan cities: Dallas, Fort Worth, and Houston. The operations, performed by the Texas State Department of Highways and Public Transportation (TSDHPT) and private contractors, included (a) two paint striping operations by TSDHPT, (b) one thermoplastic striping project by a contractor, and (c) two installations of raised pavement markers by a contractor.

A 0.5-in color videotape recording system and a 35-mm camera were used for data collection. The videotape provided a visual record for detailed study of the maintenance operations, the equipment used, and the effect on traffic flow. The 35-mm slides and photographs provided a detailed record of equipment and vehicles used in the operations. Data were collected from several vantage points: a bucket truck, the roof of a vehicle, an in-stream moving vehicle, and the roof of a high-rise building.

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 a distance-measuring instrument. The first vehicle was positioned in the maintenance caravan to measure caravan travel times, traffic volumes, lane distributions, and delays (time period during which the caravan was stopped). The second vehicle was driven past the caravan several times. During these passes, sight distances to the caravan, caravan vehicle spacings, and total caravan length were recorded. This information, when coupled with the video data, helped to identify some of the safety problems associated with moving maintenance operations.

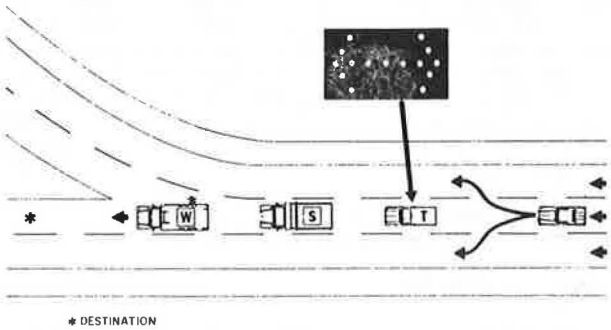
SAFETY PROBLEMS

The safety problems identified as a result of the observations are grouped in two categories: problems related to freeway design and operational problems. Specific problems in each category are discussed below.

Problems Related to Freeway Design

Freeway design elements that contribute to potential

Figure 1. Freeway-design-related problem at major interchanges.



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 in the middle lanes. Generally, ramp-related problems do not occur when the caravan is in the median lane unless there are left-hand entrances and exits.

Shoulder Lane at Entrance Ramps

Ramp drivers crossing through the caravan create a 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 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 in the acceleration lane and merged between two caravan vehicles.

Drivers who merge between caravan vehicles create two problems. First, because they have merged with the caravan, their vehicle speed is equal to that of the caravan (5-10 mph). When they merge into an open lane, they are forced to accelerate very rapidly to the higher freeway speeds. Secondly, the larger caravan vehicles may obstruct the visibility of approaching vehicles. Therefore, when trapped drivers merge into the open lane, approaching drivers may be forced to make 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 or she 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. A driver who merges left must then pass the caravan and move to the right across at least two lanes to the exit. If the driver, however, is unable to pass the caravan, he or she is forced to either miss the exit or merge with the caravan and then cross over to make the exit.

Current information provided to 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 or the length of the caravan if there is one.

Recommendations

Problems created by entrance and exit ramps can be alleviated by 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. Advance signing should provide advance warning concerning the blocked lane, and 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 later in this paper.

Major Interchanges

The problems observed at freeway-to-freeway interchanges were generally 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 or a split to the crossing freeway (see Figure 1). In the maintenance operations observed, the trailing vehicle in the caravan normally displayed a double-headed flashing arrow that encouraged 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 who elected to do so were suddenly found on the ramp leading to the crossing freeway.

Another problem occurs when a moving maintenance caravan approaching a major interchange 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 at 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 in the performance of 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 later in this paper.

Horizontal and Vertical Curvature

Horizontal Curvature

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 and degree of the curve, there is often insufficient sight distance for safe 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 approach 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 trailing vehicle stopped to provide sight distance. As the remainder of the caravan moved downstream and a large gap occurred between the trailing 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 caravan penetration.

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. Caravan length can be controlled 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 trailing vehicle stops at a point in the curve where there is sufficient sight distance for approaching motorists to leave the blocked lane. The trailing vehicle remains stopped until the leading portion of the caravan clears the curve. When sufficient sight distance is available, the trailing vehicle should move to its normal spacing.

Advance signing and controlled caravan length are discussed in greater detail later in this paper.

OPERATIONAL PROBLEMS

The second category of problems is termed "operational" because these problems are related to the manner in which the moving maintenance is performed. The 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

Problem

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 trailing vehicles on urban freeways because of their high target value and legibility distance.

The problems observed were ones of misuse or overuse. 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 that was to be used while the maintenance was performed was used in completing the entry to the freeway. This display did not always convey the proper information to approaching motorists. The same improper use 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 in 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 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.

It should be noted that placement of arrowboard 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

Problem

The movement of a 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, which indicated 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 in which the vehicles moved as a caravan from lane to lane to one in which each caravan vehicle seemed to move independently. Several freeway lanes can become affected as a result of this independent movement.

Recommendations

The development 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 the next section of this paper.

Large Spacing Between Caravan Vehicles

Problem

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 violate one of the primary purposes of caravans. At one location, all exiting vehicles (14) crossed between caravan vehicles or passed the trailing vehicle 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 depend on the maintenance operation being performed and the number of vehicles in the caravan. If excessive vehicle spacing is required, the caravan should be defined through the use of cones.

The guidelines for controlled caravan length are discussed in the next section of this paper.

Unnecessary Lane Blockage by the Caravan

Problem

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 stoppages observed ranged from a few moments to more than an hour. These work delays extend the time that the lane is closed to traffic and reduce worker safety through increased exposure.

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 by 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 the roadway.

SUMMARY OF RECOMMENDATIONS

The information discussed in this section 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 some of the operations observed. Others were developed based on engineering judgment. These recommendations should be tested in the field to assess their relative effectiveness.

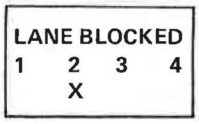
Communications

A working communications system between all moving maintenance caravan vehicles is an essential element in reducing almost all operational problems. This system should be made up of either two-way or citizens band radios, although other systems could be developed. Of the moving maintenance operations observed (not including the study of multilane closure), 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 multilane closure, no communications were available between any of the contractors' vehicles. Vehicle communications could be useful in positioning the caravan vehicles, eliminating improper arrowboard display, and communicating caravan location to ramp control and advance signing vehicles.

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. 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 (1), the lane occupied by the moving maintenance caravan could be identified. This can be accomplished by using either a static sign with a black legend on an orange background or a changeable-message sign with a message similar to the following:



Although the above message would be similar to that used on an eight-lane freeway with four lanes

Figure 2. Ramp control (*) with continuous frontage roads.

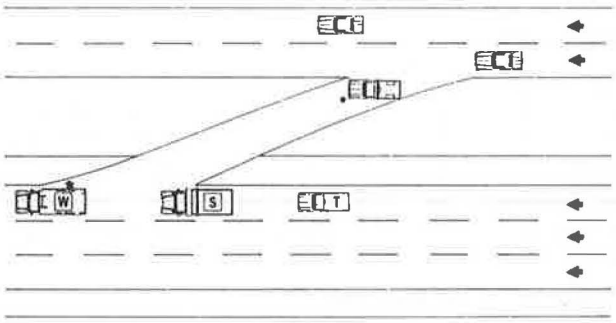
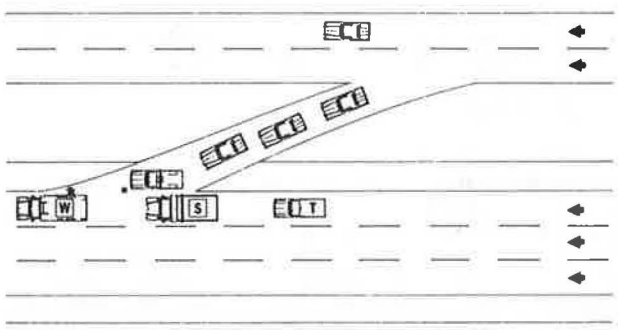


Figure 3. Ramp control (*) with discontinuous frontage roads.



per direction, it is recommended that this type of sign be field tested on urban freeways with three or more lanes per direction. The sign, mounted on a vehicle, should be located upstream from the last caravan (trailing) vehicle. A distance of at least 1000 ft will ensure 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 that have two lanes per direction, a flashing arrowboard should provide sufficient advance warning.

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 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 2). 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 3). 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 warning vehicles to provide adequate information to entering motorists in order to reduce confusion and merge speeds. In this situation, the ramp control vehicle performs a function similar to that performed by the advance warning vehicle.

Caravan Positioning Procedures (Caravan Entry and Exit)

The movement of the caravan onto or off of the freeway would be a coordinated effort in which the trailing vehicle provides 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), and the vehicles should be arranged in the proper order from ramp controller to trailing vehicle. The initial movement of the caravan should be coordinated between vehicles and the arrowboard 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 begin, the trailing vehicle making the first movement. The remaining vehicles should then complete a "last-to-first" movement until all caravan vehicles, from trailing vehicle to applicator vehicle, have completed entry. Radio communication should be maintained to ensure 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 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 trailing vehicle leaves the section and the close spacing is completed, the caravan is prepared to begin the lane change. The lane change is initiated by the trailing 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 display. 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 ensure 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)

Controlling the length of moving maintenance caravans 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, and epoxy dry time are the controlling factors in determining caravan length. Their relation can be used in the following equation:

$$L = 1.47\ vt \qquad (1)$$

where

L = caravan length (ft),
v = speed (mph),
t = dry time (s), and
vehicle spacing = L/(n - 1), where L is caravan length and n is the number of vehicles in the caravan.

For example, the minimum dry time for a quick-drying paint is 30 s. The average caravan speed for this operation is 10 mph, and three vehicles are used in the caravan (see Figure 4). Therefore,

L = 1.47 (10 mph) (30 s) = 441 (round off to 450 ft).
Vehicle spacing = 450/(3 - 1) = 225.

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

1.47 (2 mph) (2400 s) = 7056 ft or 1.34 miles (round off to 1.5 miles).

The determination of vehicle spacings in this operation is not similar to that in striping. From observations made during one raised-pavement-marker operation, use of the 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 caravan was not penetrated by crossing vehicles. The arrangement of vehicles used in this operation is shown in Figure 5.

It is desirable that all moving operations that occupy or block a lane (or lanes) of traffic include one advance signing vehicle and one ramp control vehicle. The location of these vehicles is not included in caravan length because their location does not influence normal traffic flow. The ramp control vehicle is the lead vehicle when not at a ramp location.

There are two possible options in the control of caravan length to reduce problems associated with sight distances resulting from horizontal and vertical curvature. The first option is to use minimum length and normal operations. In this method, it is assumed that the advance signing vehicle provides the information and sight distance required for a safe operation.

The second method of length control requires that the trailing vehicle and the advance warning vehicle stop for a short period of time. The 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 1000-ft sight distance in addition to the normal vehicle spacing (2). This distance is consistent with other research recommendations. For example, if normal spacing between the trailing vehicle and the next caravan vehicle were 250 ft, the trailing vehicle would remain stopped until a separation of 1250 ft (1000 ft + 250 ft) resulted. This distance could be determined 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 in relation to sight distance and geometrics (horizontal and vertical curvature). Should the advance signing prove effective, increased separation and stoppage of the trailing vehicle in the main lane may not be necessary.

Figure 4. Moving maintenance caravan with three caravan vehicles and short dry time.

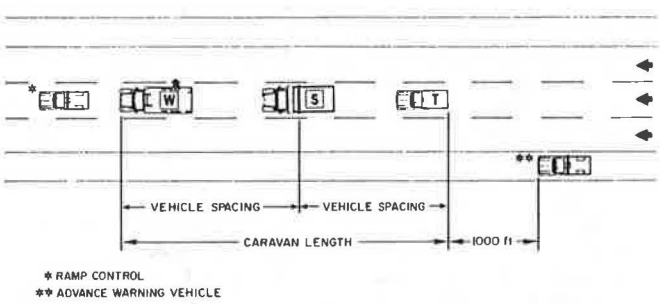
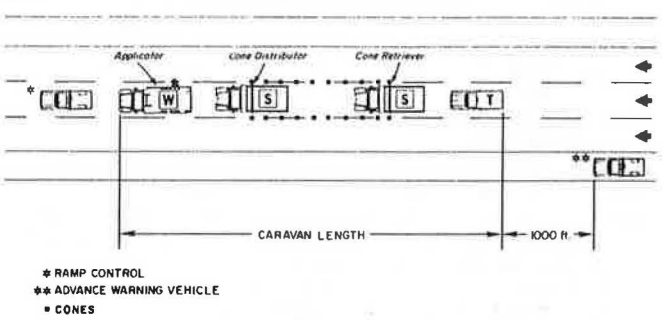


Figure 5. Moving maintenance caravan with four caravan vehicles and long dry time.



Specialized Interchange Signing (Major Interchanges)

Specialized signing is needed to provide approaching motorists with information concerning the proper lane designations for access to the desired freeway. The signing currently used is insufficient. Additional research is required to achieve 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 used in an attempt to provide safer conditions for both the worker and the nonworker. However, there has been no specialized training or guidance for crews responsible for the completion of moving maintenance operation. These individuals learn their procedures from field experience and from the knowledge of others. Because of this educational process, each crew has its individual maintenance procedures. These differences vary in the procedures, equipment (type and amount), and products used.

A specialized training program for individuals involved with moving maintenance operations has been developed and, if used, would provide a basis for uniform operation. These standards would in turn provide guidelines for contractors and thus maintain a uniformity in operations. Such training includes caravan entry and exit procedures, a basic knowledge of sight distance, vehicle spacing and caravan length, equipment operation and message understanding (arrow panels, changeable-message signs, etc.), placement and retrieval of traffic-control devices, and flagging procedures.

ACKNOWLEDGMENT

We would like to express our appreciation to Bobby

Hodge and Robert Jenkins (District 2), Hunter Garrison (District 12), and Milton Watkins (District 18) and the staffs of their respective TSDHPT districts for their assistance and cooperation in the study.

The research documented in this paper was part of a highway planning and research study conducted for TSDHPT. Tom Newborn of TSDHPT is also acknowledged for his guidance and assistance in all phases of the research study.

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

Sight-Distance Requirements at Lane-Closure Work Zones on Urban Freeways

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Findings of field studies conducted to evaluate the effects of sight distance to lane closures at urban freeway work zones are presented and discussed. The studies investigated the interaction of sight distance with traffic volume and various work-zone traffic-control features (e.g., advance signing and arrowboards). The studies were conducted at 15 maintenance work zones of freeways in Houston, Dallas, Fort Worth, San Antonio, and Corpus Christi, Texas. The studies revealed that, as sight distance to a lane closure decreases, more and more drivers are "trapped" in the closed lane at the taper area. At sites where the sight distance was less than 1000 ft, for example, up to 80 percent of the traffic in the closed lane did not leave the closed lane until reaching the immediate vicinity of the lane-closure taper. Sight distance becomes even more critical as traffic volumes increase. Based on the study findings, a minimum desirable sight distance of 1500 ft was recommended for lane-closure work zones on freeways. The studies also suggest that advance signing for lane closures is only partly effective. In the studies, only half of the affected drivers responded to the advance signing evaluated. Arrowboards were also studied and proved to be effective traffic-control devices for lane closures where sight distance is adequate, since they encourage early lane changing.

Maintenance operations performed on urban freeways often require the temporary closing of one or more travel lanes. In these situations, motorists should be encouraged by the use of effective traffic-control devices (e.g., advance signing, cone taper, and arrowboards) to vacate the closed lanes in advance of the work area. If the traffic-control system fails, severe operational problems can result as high-speed traffic is surprised by the lane closure and "trapped" in the closed lane.

A series of field studies was conducted to evaluate current traffic-control practices at lane-closure work zones on urban freeways in Texas. The studies identified problem areas and provided input for the development of improved traffic-control practices.

PRELIMINARY STUDIES

Preliminary field studies were conducted at 15 lane-closure work zones on urban freeways in Dallas, San Antonio, Fort Worth, and Corpus Christi. In these studies, a research team documented the geometrics and traffic control used at each work site and measured the sight distances to the lane closure. All 15 work zones studied involved one- or two-lane closures on three-lane sections.

A field crew was also deployed at the work zones to manually collect volume and lane distribution data at points upstream of and at the beginning of the lane closure. These data, collected for several hours at each site, were used to determine the performance of the various traffic-control devices. The effectiveness of a control device was judged by its success in encouraging drivers in the closed lane to vacate the lane upstream of the taper area.

The data collected at the 15 work zones revealed that sight distance had a significant influence on driver behavior at lane-closure work zones. (Sight distance is defined as the distance from the beginning of the cone taper to the point where a driver can identify that his or her lane is closed, provided the line of sight is not obstructed by another vehicle.) This influence is shown in Figure 1, which plots the percentage of vehicles still in the closed lane 200 ft upstream of the cone taper versus sight distance. The figure indicates that as sight distance decreased more and more drivers were trapped in the closed lane until reaching the taper area, where these drivers had to "force" their way into an adjacent open travel lane.

As sight distance was restricted to less than about 1500 ft, the percentage of trapped drivers increased moderately. As the sight distance was reduced even more (to less than 1000 ft), the percentage of trapped drivers rapidly increased. At those work zones with a sight distance between 600 and 800 ft, for example, up to 80 percent of the traffic in the closed lane still occupied the closed lane 200 ft upstream of the cone taper.

Figure 1 also shows that the sight distances at the 15 randomly selected work zones varied considerably, from 650 to 5100 ft. Several of the work zones had relatively short sight distances. In fact, 4 of the work zones had sight distances of less than 1000 ft.

The preliminary field studies also provided insight into the effects of traffic volume on traffic operations at lane-closure work zones, as shown in Figure 2. (One of the 15 study sites was omitted from the evaluation because of inconsistencies resulting from the presence of an exit ramp near the taper area.) Figure 2 suggests that traffic volume