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Contents

Authors of the Papers in This Record

DeLannoy, Henry, Belgium Ministry of Public Works, Rue de Geneve 4 BP10, Brussels B 1140, Belgium
Dudek, Conrad L., Texas Transportation Institute, Texas A&M University, College Station, TX 77843
Faulkner, Michael J.S., Texas Transportation Institute, Texas A&M University, College Station, TX 77843
Frédéric, Claude, Centre de Recherches Routières, Boulevard de la Woluwe 42, Brussels 1200, Belgium
Hoel, Lester A., Virginia Highway and Transportation Research Council, Box 3817, University Station, Charlottesville, VA 22903
Huddleston, Nada D., Texas Transportation Institute, Texas A&M University, College Station, TX 77843
Labeau, Alain, Belgium Ministry of Public Works, Rue de Geneve 4 BP10, Brussels B 1140, Belgium
Nielsen, Doug, Equipment and Procurement Division, Arkansas State Highway and Transportation Department, P.O. Box 1261, Little Rock, AR 72203
Ray, G.L., Louisiana Department of Transportation and Development, P.O. Box 44245, Capitol Station, Baton Rouge, LA 70804
Reichert, Jean, Centre de Recherches Routières, Boulevard de la Woluwe 42, Brussels 1200, Belgium
Richards, Stephen H., Walton and Associates, 12200 Northwest Freeway, Suite 531, Houston, TX 77092; formerly at Texas A&M University
Rissel, Martin C., Byrd, Tallamy, MacDonald and Lewis, 2921 Telestar Court, Merrifield P.O. Box 504, Fairfax County, VA 22116
Roberts, Gary L., Virginia Highway and Transportation Research Council, Box 3817, University Station, Charlottesville, VA 22903

Driver Understanding of Work-Zone Flagger Signals

NADA D. HUDDLESTON, STEPHEN H. RICHARDS, AND CONRAD L. DUDEK

The results of a human-factors laboratory study conducted in Texas to evaluate driver understanding of 13 work-zone flagger signals are reported. This was an exploratory study in which 123 motorists participated and 23-73 motorists viewed each signal. The signals evaluated included (a) seven standard signals recommended in the 1978 national Manual on Uniform Traffic Control Devices (MUTCD), (b) two signals recommended in the 1973 Texas MUTCD but not included in the 1978 national MUTCD, (c) two signals recommended for use by police, and (d) two nonstandard signals that combined standard signals from the 1978 national MUTCD. A STOP or SLOW sign paddle, a red flag, and/or hand motions were used to perform the various signals. The results indicated that (a) most drivers understood all seven of the 1978 MUTCD signals except signal 2 (Stop Traffic) and signal 9 (Alert Traffic) (both signals required the use of a flag alone), (b) exclusion of the two signals in the 1973 Texas MUTCD from the current Manual was in the best interest of work-zone safety, (c) the two police signals were understood by most drivers but are not recommended for use at this time, and (d) the two nonstandard signals showed no advantage over the 1978 MUTCD signals. The study indicated that most of the signals that involved the use of a STOP-SLOW sign paddle and/or hand motion were understood by the drivers but the signals in which a flag alone was used were less effective.

Flaggers (or flagmen) are used at some highway work zones to guide and direct motorists. They protect the safety of the work crew and encourage safe and efficient traffic operation in the work zone (e.g., continuous traffic flow at reduced speeds).

The Manual on Uniform Traffic Control Devices for Streets and Highways (national MUTCD) presents guidelines for the use of various hand signals and signalizing devices for work-zone traffic control. The current (1978) edition of the national MUTCD (1) recommends several standard signals, including three signals used to stop traffic.

Various police agencies have developed guidelines for traffic-control hand signals that could be used for work-zone traffic management. For example, the police training school at the Northwestern University Traffic Institute has recommended standard police hand signals for directing traffic to stop and to turn left (2). Police hand signals, however, are normally not used by work-zone flaggers.

STUDY PURPOSE

A human-factors laboratory study was developed to evaluate drivers' understanding of various flagger signals and signaling devices for work-zone traffic control. The study evaluated 13 signals, including

1. Seven standard signals recommended in the 1978 national MUTCD,
2. Two signals recommended in the original 1973 Texas MUTCD (3) but not included in the 1978 national MUTCD or the 1980 Texas MUTCD (4),
3. Two signals recommended for use by police by the Northwestern University Traffic Institute, and
4. Two nonstandard signals that combine standard signals from the 1978 national MUTCD.

The seven standard signals from the 1978 national MUTCD and the two signals from the 1973 Texas MUTCD involve the use of a red flag or a STOP or SLOW sign paddle. Some of these signals also require hand motions to supplement the flag or paddle. The two police signals evaluated are performed by using only hand motions. The two nonstandard signals studied involve the simultaneous use of both a flag and a STOP or SLOW sign paddle. Figure 1 illustrates and describes the 13 signals evaluated.

STUDY DESCRIPTION

The various signals were performed at a proving-ground facility by a trained flagger, who was situated in a roadside setting but not in an apparent work-zone environment. The flagger wore an orange vest and a hard hat.

Each signal was videotaped in color from inside a stationary vehicle from a distance close enough so that all signals would be clearly visible on the videotape recording. Study participants were shown the taped signals and asked what they would do in response to each signal.

STUDY ADMINISTRATION

The study was administered to licensed drivers in Bryan-College Station, Texas, at a shopping mall and a local driver licensing center. A total of 123 motorists participated in the study, and 23-73 motorists viewed and interpreted each signal. (All but two of the signals were viewed by at least 50 motorists.)

Table 1 summarizes the demographic characteristics of the study sample. The drivers participating in the study, on the average, were younger and better educated than the population of licensed drivers in the United States and Texas.

STUDY RESULTS

Tables 2-4 present the study results for the 13 signals evaluated (Figure 1). The data indicate that the most effective signal evaluated, in terms of driver understanding, was signal 1, which involved the use of a STOP sign paddle and hand motion to stop traffic. This signal implied a "stop" message to 100 percent of the 73 drivers who saw it. The least effective signal was signal 9, which involved the use of a red flag to alert and slow traffic. Only 31 percent of the 23 drivers who viewed this signal understood its intended meaning.

Signals for Stopping Traffic

Five of the 13 signals evaluated in the study were intended to stop traffic (signals 1 through 5 in Figure 1). Table 2 summarizes driver understanding of these signals. The data in Table 2 indicate that four of the five signals (signals 1, 3, 4, and 5) were understood by at least 90 percent of the drivers. These signals involved the use of a STOP sign paddle and/or hand motion.

Signal 2, on the other hand, implied a "stop" message to only 74 percent of the drivers. This signal involved the use of only a red flag and is one of the signals recommended for use in the 1978 national MUTCD.

It is interesting to compare the performance of signals 2 and 3. Both involved the same flagging motion, but in signal 3 this flagging motion was supplemented with a hand motion. This hand motion apparently enhanced driver understanding: The data in Table 2 indicate that 91 percent of the drivers understood signal 3 (flag and hand motion) whereas only 74 percent understood signal 2 (flag only).

Signals for Encouraging Traffic to Proceed

Two signals from the 1978 national MUTCD intended to

Figure 1. Flagger signals evaluated in study.

①

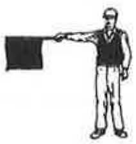
Signal Intent: Stop traffic

Description: The flagger holds the sign paddle in a stationary position with the arm extended horizontally away from the body. The free arm is raised with the palm toward approaching traffic.

Device(s) Used: STOP Sign Paddle and Hand

Source: 1980 *Texas MUTCD*

②



Signal Intent: Stop traffic

Description: The flagger faces traffic and extends the flag horizontally across the traffic lane in a stationary position so that the full area of the flag is visible hanging below the staff.

Device(s) Used: Flag

Source: 1980 *Texas MUTCD*

③

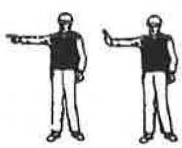
Signal Intent: Stop traffic

Description: The flagger faces traffic and extends the flag horizontally across the traffic lane in a stationary position so that the full area of the flag is visible hanging below the staff. The free arm is raised with the palm toward approaching traffic.

Device(s) Used: Flag and Hand

Source: 1980 *Texas MUTCD*

④



Signal Intent: Stop traffic

Description: The flagger points with his arm and finger and looks straight at the driver. He watches the driver and holds this point until seen. Then, the pointing hand is raised (but not the whole arm) so that the palm is toward the driver.

Device(s) Used: Hand

Source: Police Handbook

⑤

Signal Intent: Stop traffic

Description: The flagger faces traffic and extends the flag horizontally across the traffic lane in a stationary position so that the full area of the flag is visible hanging below the staff. The left arm is raised with the STOP sign paddle facing approaching traffic.

Device(s) Used: STOP Sign Paddle and Flag

Source: Combination of two signals from the 1980 *Texas MUTCD*, resulting in a non-standard signal.

⑥

Signal Intent: Encourage traffic to proceed

Description: The flagger stands parallel to the traffic movement, and with flag and arm lowered from view of the driver, motions traffic ahead with his free arm. The flag is not used to signal traffic to proceed.

Device(s) Used: Hand

Source: 1980 *Texas MUTCD*

⑦

Signal Intent: Encourage traffic to proceed

Description: A SLOW sign paddle is held in a stationary position with the arm extended horizontally away from the body. The flagger motions traffic ahead with his free hand.

Device(s) Used: SLOW Sign Paddle and Hand

Source: 1980 *Texas MUTCD*

⑧

Signal Intent: Alert and slow traffic

Description: The flagger holds the SLOW sign paddle in a stationary position with the arm extended horizontally away from the body.

Device(s) Used: SLOW Sign Paddle

Source: 1980 *Texas MUTCD*

⑨

Signal Intent: Alert and slow traffic

Description: The flagger faces traffic and slowly waves the flag in a sweeping motion with the extended arm from the shoulder level to straight down without raising the arm above a horizontal position.

Device(s) Used: Flag

Source: 1980 *Texas MUTCD*

⑩

Signal Intent: Alert and slow traffic

Description: The flagger faces traffic and slowly waves the flag in a sweeping motion with the arm extended from the shoulder level to straight down without raising the arm above a horizontal position. The SLOW sign paddle is held in a stationary position with the arm extended horizontally away from the body.

Device(s) Used: SLOW Sign Paddle and Flag

Source: Combination of two signals from the 1980 *Texas MUTCD*, resulting in a non-standard signal.

⑪

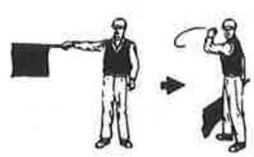
Signal Intent: Alert traffic

Description: The flagger faces traffic and waves the flag in a sweeping motion of the arm across the front of the body without raising the arm above a horizontal position.

Device(s) Used: Flag

Source: 1973 *Texas MUTCD* (Not included in the 1980 *Texas MUTCD*)

⑫



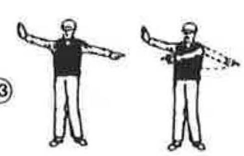
Signal Intent: Slow traffic

Description: The flagger faces traffic and extends the flag horizontally across the traffic lane in a stationary position so that the full area of the flag is visible hanging below the staff. Then the flagger stands parallel to the traffic movement, and with the flag and arm lowered from view of the driver, motions traffic ahead with his free arm.

Device(s) Used: Flag and Hand

Source: 1973 *Texas MUTCD* (Not included in the 1980 *Texas MUTCD*)

⑬



Signal Intent: Encourage traffic to turn left

Description: The flagger gives the stop signal with his right arm to stop traffic in the opposing lane. Holding this stop signal, he gives a turning gesture with his left arm.

Device(s) Used: Hands

Source: Police Handbook

Table 1. Demographic characteristics of study sample.

Signal	No. of Subjects	Percent Male	Average Age (years)	Average Years of College
1	73	60	33	1.9
2	73	55	34	1.6
3	73	55	34	1.6
4	73	60	33	1.9
5	50	42	29	1.2
6	73	60	33	1.9
7	73	60	33	1.9
8	23	100	41	3.2
9	23	100	41	3.2
10	50	42	29	1.2
11	73	55	34	1.6
12	73	55	34	1.6
13	73	55	34	1.6
All	123	50	32	1.4

Table 2. Driver understanding of signals used to stop traffic.

Signal	Source	Device Used	Sample Size	Drivers Stating Intended Meaning (%)
1	1978 national MUTCD	STOP sign paddle and hand	73	100
4	Police handbook	Hand	73	94
3	1980 national MUTCD	Flag and hand	73	91
5	Combined signals	STOP sign paddle and flag	50	90
2	1978 national MUTCD	Flag	73	74

Table 3. Driver understanding of signals used to encourage traffic to proceed.

Signal	Source	Device Used	Sample Size	Drivers Stating Intended Meaning (%)
6	1978 national MUTCD	Hand	73	100
7	1978 national MUTCD	SLOW sign paddle and hand	73	93

Table 4. Driver understanding of signals used to alert and/or slow traffic.

Signal	Source	Device Used	Sample Size	Drivers Stating Intended Meaning (%)
8	1978 national MUTCD	SLOW sign paddle	23	96
10	Combined signals	SLOW sign paddle and hand	50	62
12	1973 Texas MUTCD	Flag and hand	73	57
11	1973 Texas MUTCD	Flag	73	54
9	1978 national MUTCD	Flag	23	31

encourage traffic to proceed after being stopped were evaluated (signals 6 and 7 in Figure 1). Driver understanding of these two signals is summarized in Table 3. The data indicate that both of these signals were understood by most drivers. The hand-motion signal (signal 6) was most effective; 100 percent of the drivers understood its intended meaning.

Signals for Alerting and Slowing Traffic

Five signals intended to alert and/or slow traffic were evaluated in the study (signals 8 through 12 in Figure 1). Table 4 summarizes driver understanding of these signals. The data indicate that only one of these signals, signal 8, was understood by most drivers. Signal 8, which is recommended for use in the 1978 national MUTCD, involved the use of a SLOW sign paddle.

Signals 9, 11, and 12 were least effective with respect to driver understanding. All of these signals involved the use of a red flag. The intended meaning of signal 9, which is recommended in the 1978 national MUTCD for alerting and slowing traffic, was understood by only 31 percent of the drivers.

Signal for Encouraging Traffic to Turn Left

A hand signal recommended by the Northwestern University Traffic Institute Police Training School for encouraging traffic to turn left was studied (signal 13 in Figure 1). The data show that 83 percent of the drivers understood the intended meaning of this signal.

CONCLUSIONS AND RECOMMENDATIONS

The study documented in this paper was an exploratory study of general trends in driver understanding of flagger signals. The sample size was relatively small and limited to drivers from one area of Texas, and the study evaluated drivers' understanding of "staged" flagger signals viewed from a stationary vantage point.

Nevertheless, several conclusions regarding the effectiveness of the 13 flagger signals studied can be made based on the study results.

National MUTCD Signals

Five of the seven signals recommended in the 1978 national MUTCD (signals 1, 3, 6, 7, and 8) appear to be understood by most drivers. These five signals involve the use of a STOP or SLOW sign paddle and/or hand motions.

The two signals recommended in the 1978 national MUTCD that were not generally understood by the study participants (signals 2 and 9) involve the use of only a red flag. This finding suggests that a red flag used alone is a relatively ineffective traffic-control device.

Texas MUTCD Signals (Deleted Signals)

The two signals recommended in the original 1973 Texas MUTCD, but not included in the 1980 Texas MUTCD (signals 11 and 12), were not generally understood by the drivers. The exclusion of these signals from the current editions of the national and Texas MUTCDs apparently is in the best interest of work-zone safety.

Stopping Traffic

Signal 1 (STOP sign paddle and hand motion) and signal 3 (flag and hand motion) were understood by most drivers in the study. Both of these signals are included in the 1978 national MUTCD. Based on the study results, their continued use is recommended.

Signal 2 (flag only), on the other hand, is apparently not understood by many motorists even though it is included in the 1978 national MUTCD. Based on this finding, the use of signal 2 is discouraged.

Signal 4 (police hand motion) and signal 5 (STOP sign paddle and flag) performed well in the study in terms of driver understanding. However, these signals would probably not offer any advantages over signal 1 or signal 3; therefore, signals 4 and 5 are not recommended for work-zone traffic control.

Encouraging Traffic to Proceed

Signal 6 (hand motion) and signal 7 (SLOW sign paddle and hand motion) were understood by most motorists. Their use at work zones for encouraging stopped traffic to proceed is supported by the study results. Both signals 6 and 7 are recommended in the 1978 national MUTCD.

Alerting and Slowing Traffic

Signal 8 (SLOW sign paddle) was the only signal for alerting and slowing traffic that was understood by most drivers. This signal is recommended in the 1978 national MUTCD, and its use is supported by the study results.

Four other signals for alerting and slowing traffic were tested (signals 9 through 12), but none of these signals were generally understood by motorists in the study. Their use, therefore, is not recommended. One of these deficient signals, signal 9 (flag only), is included in the 1978 national MUTCD.

Encouraging Traffic to Turn Left

The police hand signal for encouraging traffic to turn left was understood by more than 80 percent of the drivers. This signal and others currently used by police show promise for work-zone traffic control.

Needed Messages

The 1978 national MUTCD addresses only three basic flagging messages: stop, slow, and proceed. Thus, the functions of the work-zone flagger are currently limited. Consideration should be given to developing signals that convey other messages, such as (a) change lanes or merge into one lane, (b) turn left or right, (c) maintain speed, (d) detour or divert, and (e) use shoulder.

Training

The work-zone flagger performs a vital function in promoting traffic safety and operational efficiency. Unfortunately, flagging is viewed by many as a menial, relatively unimportant task. The least experienced or productive worker is often assigned the flagging duty without receiving instruction on proper traffic-control procedures. Flagger morale is usually very low.

It is recommended that the image and effectiveness of the flagger be improved. Proper training and instruction for all flaggers is essential. They should be familiar with proper work-zone traffic-control techniques and devices and should know how to use these tools to protect the safety of the work crew and the motoring public. Flaggers should have a basic knowledge of traffic-flow characteristics (e.g., speed, volume, and capacity) and how these characteristics relate to efficient work-zone traffic operation.

Job Title

It is also suggested that "flaggers" or "flagmen" be referred to by a more descriptive term, one that better reflects their function and importance (e.g., traffic specialists, traffic control specialists, or traffic controllers). In many instances, the flagger is the most important member of the work crew. He or she is responsible for traffic safety and operations at the work zone and for promoting public understanding and acceptance of the work-zone operation.

Attire

It should be noted that, in addition to driver understanding, other factors influence motorist reaction to a particular flagger signal. Flagger appearance is one of these factors. A flagger should be highly visible in the work-zone environment and command the attention and respect of passing motorists. As a minimum, a flagger should be attired in accordance with MUTCD guidelines (e.g., wear an orange safety vest and optional white hard hat). The development of a special flagger uniform may be the best means, however, of promoting flagger visibility and respect. In fact, special uniforms (white overalls and orange vests) have been worn by flaggers at maintenance work zones on freeways in Houston with reported success (5).

Other Considerations

The work-zone environment (e.g., type of work, presence of a work crew, and sign and barricade layout) may also affect motorist reaction to a particular flagger signal. The length of viewing time and viewing distance are important. In addition, traffic conditions (i.e., speed and volume) may influence drivers' reaction to the signal.

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Flashing Arrowboards in Advance of Freeway Work Zones

MICHAEL J.S. FAULKNER AND CONRAD L. DUDEK

The results of controlled field studies conducted by the Texas Transportation Institute to evaluate the effectiveness of flashing arrowboards located in advance of lane-closure work zones are reported. The distances in advance of the work zone ranged from 450 to 4000 ft. The effects of the supplemental arrowboard were compared with the effects of arrowboards placed in the closure at the end of the taper in each blocked lane. The results indicate that a supplemental arrowboard placed in advance of the beginning of a taper can be extremely effective in shifting traffic from the closed lane if the sight distance to the arrowboard improves the effective sight distance to the work zone. The supplemental arrowboard can be placed up to 2500 ft in advance of the taper to increase the effective sight distance to the work zone. Placement more than 2500 ft in advance of the work zone may result in drivers moving back into the blocked lanes.

Arrowboards have been the subject of many recent research reports that cover a wide range of topics, including design, human-factors considerations, and application guidelines. The results have been very positive and indicate that arrowboards do have a very high target value and that motorists respond positively to arrowboard displays. Two of these reports differ on the most effective placement of a flashing arrowboard. Knapp and Pain (1) recommend the placement of the arrowboard at the beginning of the taper; Graham, Megletz, and Glennon (2) recommend that the most effective arrowboard placement is 100-500 ft in advance of the beginning of the taper. A study was therefore conducted on I-35 in Austin, Texas, to further evaluate arrowboard placement.

STUDY APPROACH

Controlled field studies were conducted by a group of Texas Transportation Institute researchers on I-35 in Austin, Texas, to evaluate the effectiveness of flashing arrowboards used in advance of work zones that require a lane closure. Figures 1 and 2 show the two work sites and the relative location of all traffic-control devices used at each site. Thirteen controlled field studies were conducted at the two work sites. Seven arrowboard arrangements were studied at site 1 and six at site 2.

The Texas State Department of Highways and Public Transportation (TSDHPT) required one arrowboard to be located and operating in each of the closed lanes at the end of or within the taper. This requirement restricted the capability of the study to isolate the effects of only the arrowboard in advance of the beginning of the taper. Data collected at each site while arrowboards were in this required arrangement represented the base response. These data included the effects of the advance signing and permitted a comparison to be made between the base signing effectiveness and the response to a supplemental arrowboard positioned in advance of the beginning of the taper.

The data collected during each of the studies consisted of freeway volume counts, lane distributions, and sight distances to the arrowboards. Volume counts and lane distribution data were collected at count stations located upstream from the first taper. Stations were also located at all freeway access points in order to record entering and exiting vehicles; this provided a closed system for data analysis. The lane distribution data provided information concerning lane occupancy at each station so that the effects of the arrowboards could be determined. The sight distances to the arrowboards were determined by an observer traveling in a vehicle equipped with a distance-measuring instrument. These data, when compared with each arrowboard arrangement studied, reflected the relations between the lane distribution of each supplemental arrowboard location and the corresponding effective sight distance.

The data for each arrowboard arrangement were collected during 60-min intervals. After each set of data was collected, the supplemental arrowboard was repositioned. A 15-min gap between arrowboard repositioning and data collection was provided in order for the data to represent normal traffic flow.

The data representing the effectiveness of a supplemental arrowboard were collected when the additional arrowboard was positioned at distances ranging from 450 to 4000 ft in advance of the beginning of the taper.

STUDY RESULTS

The results from both sites indicated that the sight distance to an arrowboard, and thus the driver's perception of a lane closure, influence the lane-changing behavior of approaching motorists. The data collected during the supplemental arrowboard studies are shown in Figures 3 and 4.

It can be seen, from these figures, that the advance signing and arrowboard placement normally used by the Austin District of SDHPT reduced the traffic in the closed lane 40 percent at site 1 (Figure 3) and approximately 30 percent at site 2 (Figure 4). With these percentages representing the base signing effectiveness measured at 2000 ft in advance of the beginning of the taper, a comparison of the effects of the supplemental arrowboard at different locations was made for each site. Figures 3 and 4 each show one such comparison. At site 1, when the supplemental arrowboard was placed 2000 ft in advance of the beginning of the taper, there was a 60 percent reduction in traffic in the closed lane (20 percent less than normal). At site 2 a 65 percent reduction (35 percent less than normal) resulted after the supplemental arrowboard was placed 2000 ft in advance of the beginning of the taper. This reduction of traffic in the closed lane was caused by the advanced arrowboard placement and an increased effective sight distance. The effective sight distance in this case is the sight distance to the arrowboard that indicates a downstream hazard or work zone to the motorist.

Figures 5 and 6 show the relation between traffic remaining in the closed lane and effective sight distances to the work zone. The bar graphs represent the percentage of traffic remaining in the blocked lane at 2000 ft in advance of the beginning of the taper for each of the supplemental arrowboard arrangements studied. The line graph, in comparison, illustrates the effective sight distance to the work zone for each of the corresponding supplemental arrowboard arrangements. The effective sight distance and percentage of remaining traffic in the blocked lane for the required arrowboard locations are illustrated as base levels (horizontal lines) on the graph.

FINDINGS

The national Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) (3) section on flashing arrowboards deals primarily with minimum design standards. The need for and the location of an arrowboard are optional. The possible need for a supplemental arrowboard upstream from the beginning of a cone taper is not addressed. The need for and location of arrowboards or even a supplemental arrowboard depend on the horizontal and vertical alignment upstream from a work zone and should be determined during the preparation of a traffic control plan.

Figure 1. Site 1 base condition.

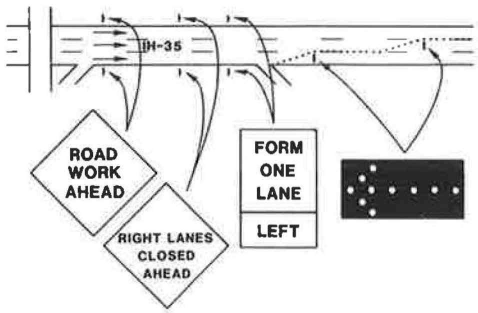
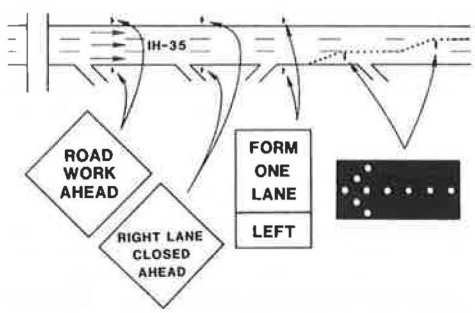


Figure 2. Site 2 base condition.



The results of the studies indicate that the use of a supplemental flashing arrowboard in advance of the beginning of a cone taper for right-side and left-side closures can be effective in shifting approaching traffic out of a closed lane. This improved effectiveness is, however, based on the supplemental arrowboard providing an increased effective sight distance to the work zone.

It is desirable to use a supplemental arrowboard when the effective sight distance to the work zone is less than 1500 ft. However, since the sight distance to each work zone varies with vertical and/or horizontal alignment, it is not possible to establish a set standard location for a supplemental arrowboard.

In one study, when a supplemental arrowboard was positioned at 4000 ft in advance of the beginning of the taper, some of the traffic that had vacated the blocked lane returned to the blocked lane before reaching the closure. Therefore, whenever a supplemental arrowboard is used, a field evaluation should be conducted to ensure a minimum sight distance (1500 ft) and to determine whether traffic is moving back into the closed lane. If vehicles are returning to the closed lane, the distance from the beginning of the taper to the supplemental arrowboard is excessive and the supplemental arrowboard should be relocated closer to the beginning of the taper.

RECOMMENDATIONS AND CONCLUSIONS

The research indicates that the placement of an arrowboard in advance of the beginning of a taper is beneficial only when the effective sight distance to the work zone is improved. The minimum allowable sight distance for urban freeway operation is 1000 ft [this has been supported in related studies such as that by McGee and others (3)]. The desired minimum sight distance to the work zone is 1500 ft.

Locating an arrowboard in advance of the beginning of the taper does not necessarily increase sight distance. The vertical and/or horizontal geometrics at each work site would control the sight distance and the resulting placement of a flashing arrowboard. Figure 7 illustrates a situation in

Figure 3. Effectiveness of supplemental arrowboard placement at site 1.

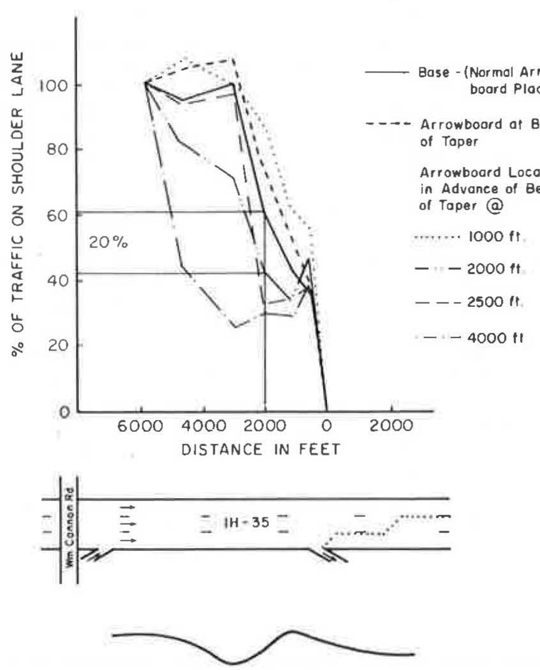


Figure 4. Effectiveness of supplemental arrowboard placement at site 2.

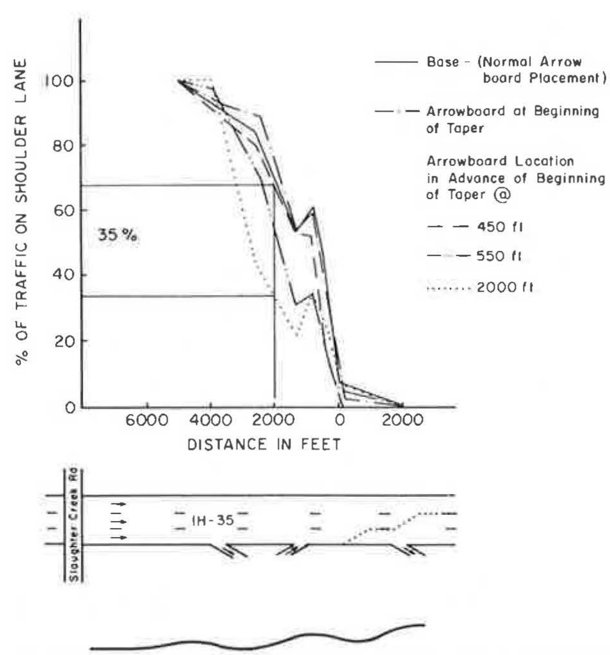


Figure 5. Site 1 supplemental arrowboard placement: lane distribution versus sight distance.

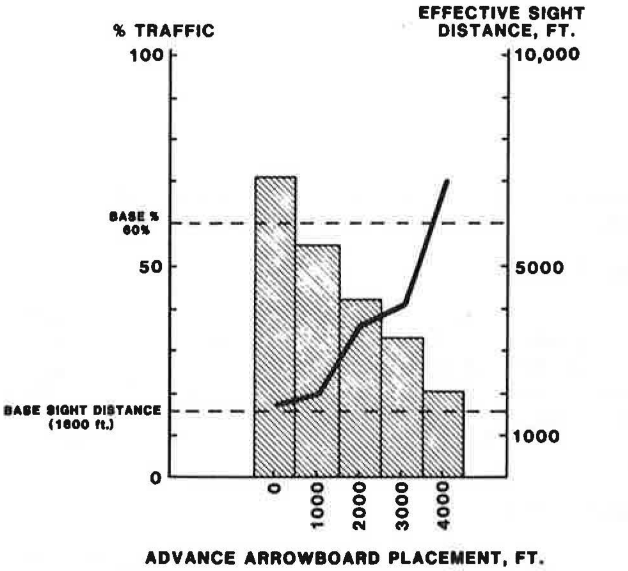


Figure 6. Site 2 supplemental arrowboard placement: lane distribution versus sight distance.

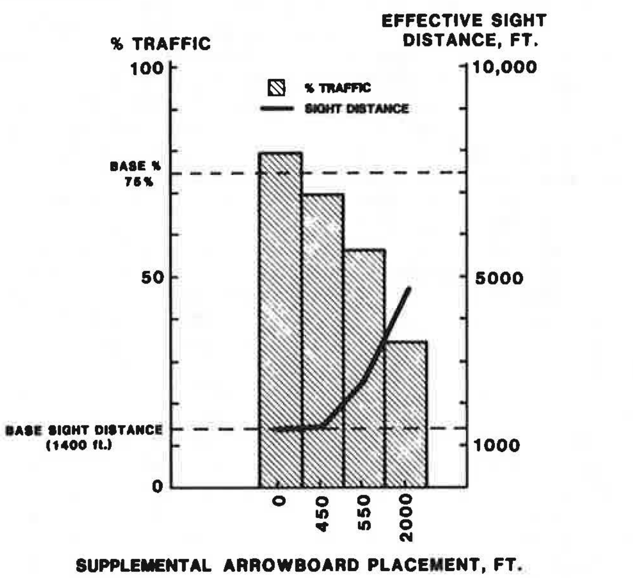


Figure 7. Typical work zone where critical arrowboard sight distance is not improved (controlled by geometrics).

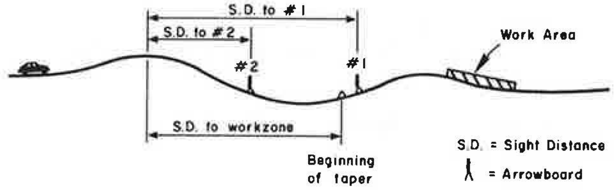


Figure 8. Typical work zone where critical arrowboard sight distance is improved.

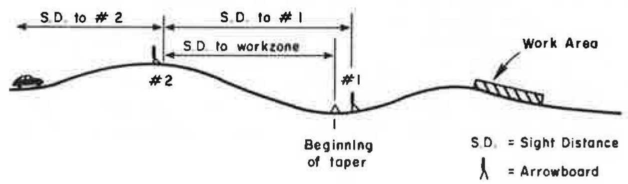
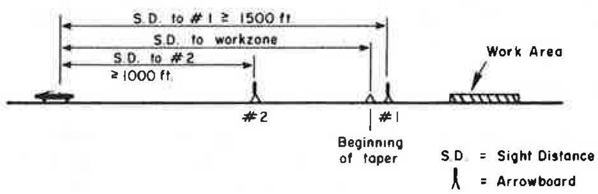


Figure 9. Typical work zone where critical sight distance is not improved (not controlled by geometrics).



which a supplemental arrowboard does not improve the sight distance to the work zone. Figure 8 shows a situation in which placing a supplemental arrowboard in advance of the taper increases the effective sight distance and is beneficial.

Work zones on a level tangent section of roadway would not require a supplemental arrowboard because the sight distance to the work zone is not critical (less than 1500 ft). Figure 9 shows this situation.

In conclusion, an arrowboard should be used at the cone taper for lane closures on urban freeways. The location of the arrowboard at the taper (at the beginning, within, or at the end) depends on the sight distance. When the sight distance to the work zone is less than 1500 ft, it is desirable to place a supplemental arrowboard on the shoulder in advance of the beginning of the taper for right-side or left-side lane closures. The supplemental arrowboard can be placed up to 2500 ft in advance of the cone taper to increase the effective sight distance to the work zone. The supplemental arrowboard should not be placed more than 2500 ft upstream because drivers have a tendency to reenter the closed lane before they reach the closure.

ACKNOWLEDGMENT

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Field Evaluation of Moving Maintenance Operations on Texas Urban Freeways

MICHAEL J.S. FAULKNER AND CONRAD L. DUDEK

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.

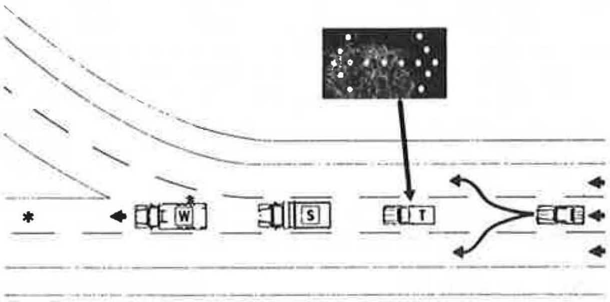
SAFETY PROBLEMS

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:

LANE BLOCKED
1 2 3 4
X

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.

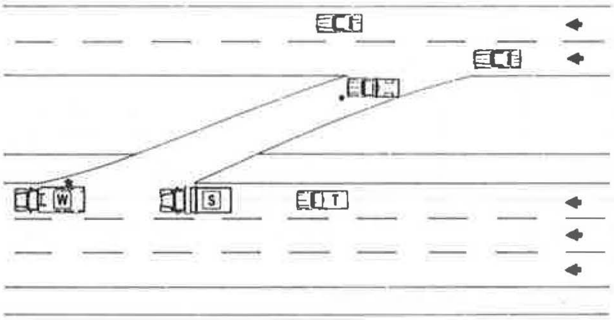
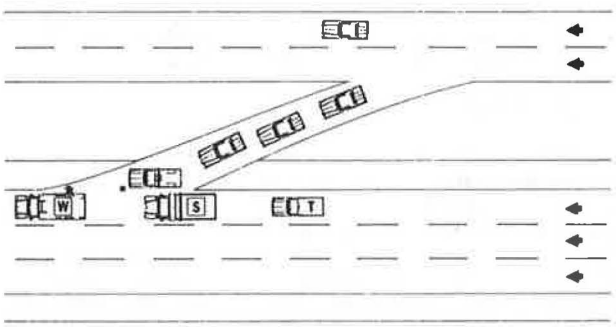


Figure 3. Ramp control (*) with discontinuous frontage roads.



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:

$$L = 1.47\ vt \tag{1}$$

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.

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

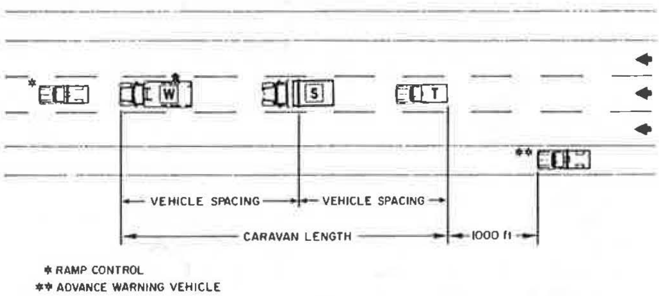
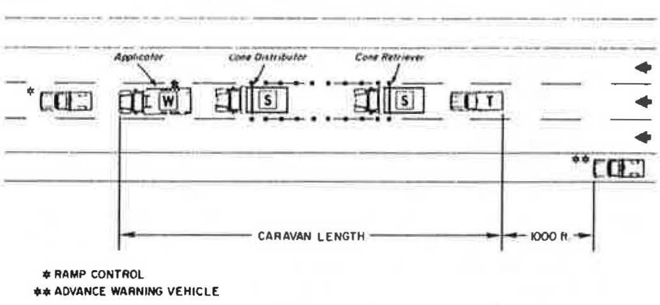


Figure 5. Moving maintenance caravan with four caravan vehicles and long dry time.



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.

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

STEPHEN H. RICHARDS AND CONRAD L. DUDEK

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.

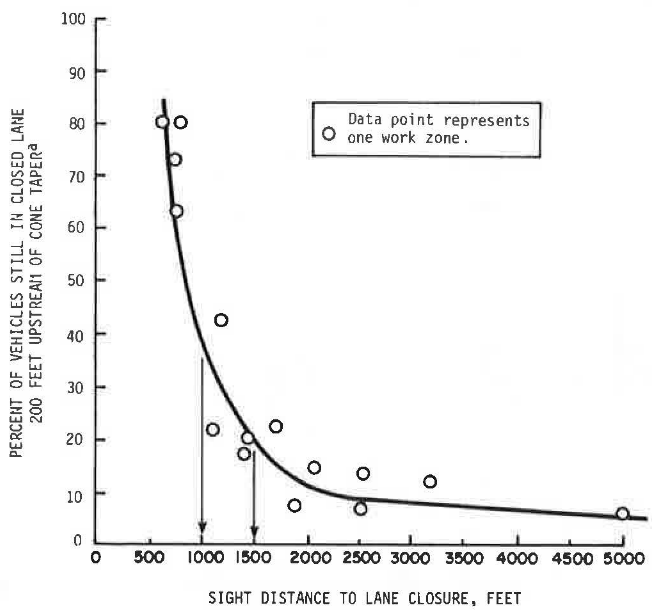
The data collected at the 15 work zones revealed that sight distance had a significant influence on driver behavior at lane-closure work zones. (Sight distance is defined as the distance from the beginning of the cone taper to the point where a driver can identify that his or her lane is closed, provided 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 did not significantly affect the percentage of closed-lane vehicles still in the closed lane very near the taper area when sight distance was greater than 1500 ft. At work zones where sight distance was less than 1500 ft, however, traffic volumes had a significant effect on occupancy of the closed lane near the taper area. As Figure 2 shows, the percentage of trapped vehicles increased very rapidly as traffic volume increased at work zones where the sight distance was less than 1500 ft.

Figure 1. Effect of sight distance to a closed lane on closed-lane occupancy.

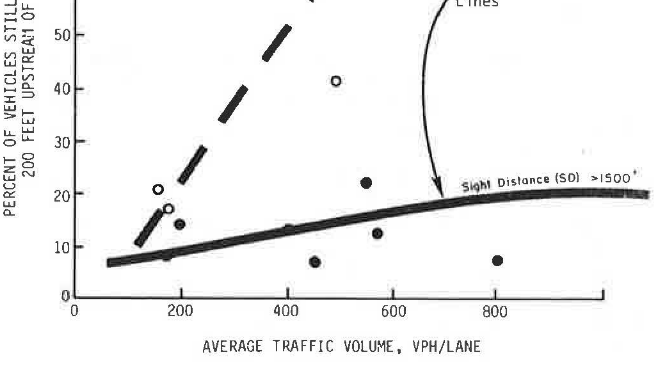


[a]Percent = $\frac{B}{A}$ where:

A = The number of vehicles in the closed lane 200 feet upstream of the beginning of the cone taper, corrected for ramp traffic.

B = The number of vehicles in the closed lane before entering the work zone, corrected for ramp traffic.

Figure 2. Effect of traffic volume on lane occupancy at lane-closure work zone.



At work zones where sight distance was greater than 1500 ft, most drivers had enough warning time to find a gap in the adjacent open lane and merge comfortably into it, regardless of the volume level (150-800 vehicles/h/lane). At work zones where sight distance was less than 1500 ft, however, drivers could move quickly out of the closed lane only under very low-volume conditions (e.g., 200 vehicles/h/lane). As traffic volume increased, there were fewer gaps available in the adjacent lane and drivers had less time to find these gaps. Therefore, more drivers were trapped.

CONTROLLED FIELD STUDIES

The field studies previously discussed revealed that sight distance is a critical factor at lane-closure work zones. They also suggested that traffic volume becomes important when sight distance is less than about 1500 ft. It should be noted, however, that there were many differences among the work zones studied, especially in site geometrics and signing. The differences made it difficult to fully assess the effects of sight distance and, in particular, the interaction of sight distance with other traffic-control features (e.g., advance signing and arrowboards). To address these concerns, a series of "controlled" field studies was developed. By using the controlled study approach, conditions at the work zone could be regulated and the effects of individual traffic-control features determined.

Study Description

The controlled field studies were conducted at a median-barrier repair worksite on I-10 in Houston. The repair work was performed by a Texas State Department of Highways and Public Transportation (TSDHPT) District 12 maintenance crew, and it required closing the median lane on a three-lane section. A 600-ft cone taper was used to close the lane, along with advance signing and an arrow sign positioned behind the taper.

Figure 3 presents a site plan for the work zone. The figure shows that a set of four advance signs were used upstream of the taper area on each side of the affected travel lanes. (The SLOW sign has been deleted from the 1978 Manual on Uniform Traffic Control Devices. If it is used, it must be accompanied by an advisory speed sign.)

Figure 4 shows a plan-profile view of the work zone. Note in Figure 4 that a vertical curve at the Bunker Hill interchange limited sight distance to the lane closure. By moving the cone taper relative to this interchange, it was possible to control the sight distance. During the studies, two taper positions were evaluated (tapers 1 and 2 in the figure), which resulted in sight distances of 900 and 1600 ft, respectively.

A step-by-step description of the study approach is presented below:

1. Data were collected before the work zone was set up to determine normal traffic flow patterns.
2. The District 12 signing crew installed the advance signs. Data were collected with the signs in place (but no lane closure) in order to evaluate the effects of the advance signing.
3. The median lane was closed (with a cone taper and static arrow sign), and data were again collected. The taper was positioned to provide a 900-ft sight distance the first day of the studies and a 1600-ft sight distance the next.
4. Finally, the static arrow sign was replaced with a flashing arrowboard sign to determine the

Figure 3. Site layout.

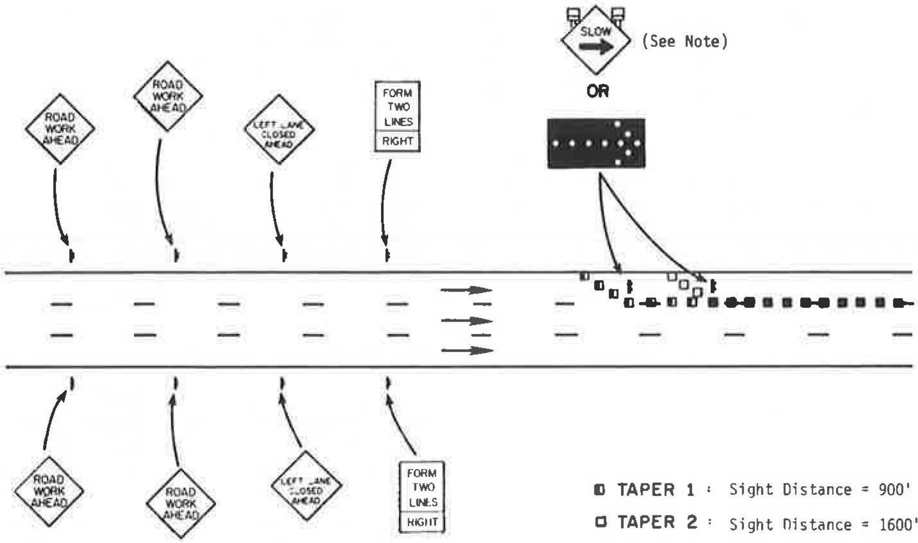
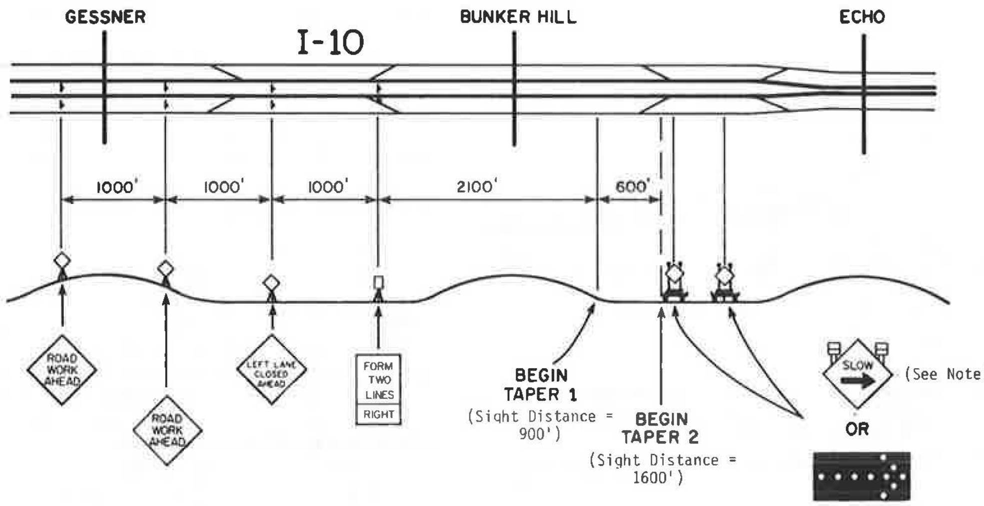


Figure 4. Plan-profile view of work zone.



effects of an arrowboard, if any. The arrowboard was evaluated under both sight-distance conditions.

During the two-day study, traffic volumes at the worksite varied somewhat. This made it possible to evaluate the effects of sight distance and the other factors (advance signing and use of a flashing arrowboard) under two volume conditions: 1000 and 3000 vehicles/h.

Data Collection

Sight distance to the lane closure was measured from a moving research vehicle by using a distance-measuring instrument (DMI) mounted in the vehicle. Several sight-distance measurements were taken, and an average sight distance was calculated for each taper location. Measurements affected by traffic interfering with the line of sight were rejected.

Lane distribution and volume data were collected at the lane closure and seven locations upstream of the closure. These data were manually counted in 5-min intervals by field crews stationed along the roadside.

The studies were conducted on two consecutive Sundays. Approximately 10 h of data (5 h/day) were collected, as follows:

Item	No. of Hours
Base date	1
Signs only	3
Signs and taper 1	2
Signs and taper 2	4

The lane distribution and volume data were reduced and analyzed to determine how much traffic was in the closed lane and when this traffic moved out of the lane in response to the signs and/or lane closure.

Findings

The controlled field studies confirmed that sight distance is an important factor at lane-closure work zones. The data gathered in the studies provided input for the development of sight-distance recommendations. The studies also revealed that the advance signing used by District 12 at the work zone (Figure 3) is only partly effective in encouraging drivers to vacate a lane. Thus, the need for adequate sight distance at lane-closure work zones is critical. As in the preliminary studies, the controlled studies revealed that traffic volume affects traffic operation more as sight distance is reduced. The studies also suggested that a flashing arrowboard, used behind the taper at lane-closure work zones, can enhance traffic operations. These findings are discussed in detail below.

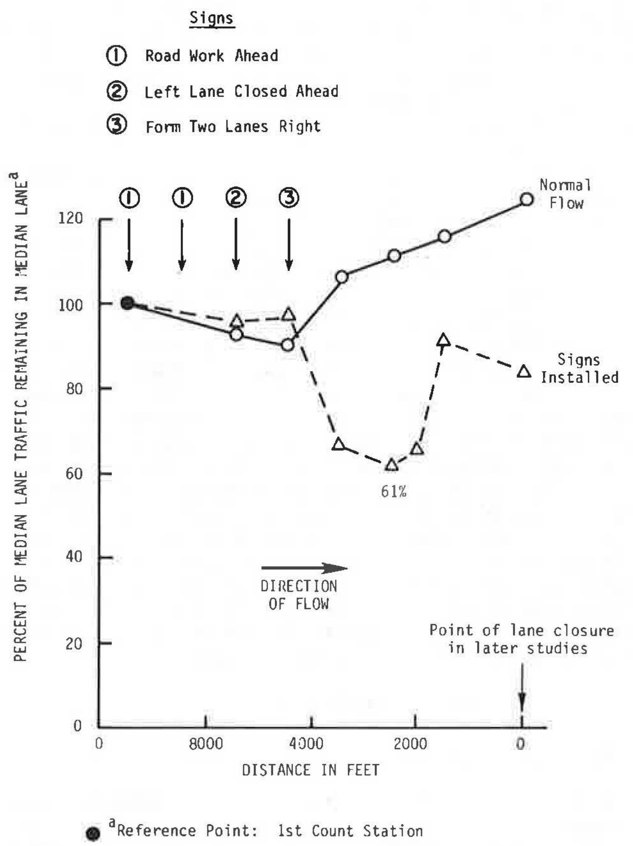
Advance Signing

Figure 5 shows the effects of the work-zone advance signing on occupancy in the median lane. From the figure, only 39 percent (100 minus 61 percent) of the drivers observed in the median lane at the first count station vacated the median lane in response to the advance signing. All of these drivers moved out of the median lane within 2000 ft of the last sign in the series.

The advance signing was evaluated before the median lane was actually closed. From Figure 5 it is seen that many drivers started moving back into the median lane approximately 2500 ft beyond the last sign. This point coincided with the crest of the vertical curve at the Bunker Hill interchange, and drivers could see that the median lane was clear for at least 2 miles ahead. There was also an entrance ramp just beyond the Bunker Hill interchange. Many of the ramp drivers, not having seen the advance signing, quickly made their way into the median lane.

Based on the data in Figure 5, it is apparent that advance signing alone will not encourage all drivers to vacate a closed lane. Many drivers apparently wait until they can identify that a lane is actually closed before they attempt a lane change. For this reason, adequate lane-closure sight distance should be provided, regardless of advance signing. Figure 5 also suggests that advance signing can be placed too far upstream of a lane closure, since drivers will begin moving back into the closed lane if they travel some distance without observing the lane closure. These studies, however, did not address the issue of sign placement relative to the point of lane closure in depth.

Figure 5. Effectiveness of advance signing used by TSDHPT District 12.



Sight Distance

Figure 6 shows the percentage of median-lane traffic still in the median lane at various distances from the lane closure for taper 1 (sight distance = 900 ft) and taper 2 (sight distance = 1600 ft). It can be seen that many drivers apparently vacated the median lane sooner when the sight distance was 1600 ft than when it was 900 ft. Under both conditions, however, the same approximate percentage of median-lane drivers still occupied the lane near the taper area. This trend, shown in Figure 6, is further illustrated in the table below, which gives the percentages of median-lane traffic still in the median lane at 1000, 500, and 200 ft upstream of the cone taper:

Sight Distance to Lane Closure (ft)	Distance Upstream of Cone Taper (ft)	Median-Lane Traffic Still in Median Lane (%)
900	1000	67
	500	51
	200	31
1600	1000	58
	500	37
	200	31

The table indicates that 31 percent of the median-lane traffic still occupied the median lane 200 ft upstream of the cone taper under both sight-distance conditions.

The data presented in Figure 6 and the table above were collected while the advance signing used by District 12 was in place upstream of the lane closure and a static arrow sign was positioned behind the cone taper. The data represent two volume conditions at the site: 1000 and 3000 vehicles/h.

The results of the controlled sight-distance studies were fairly consistent with those of the preliminary studies. They indicate that sight distances in the 900- to 1600-ft range are tolerable, but that many motorists will still be trapped in the

Figure 6. Effect of sight distance on median-lane occupancy.

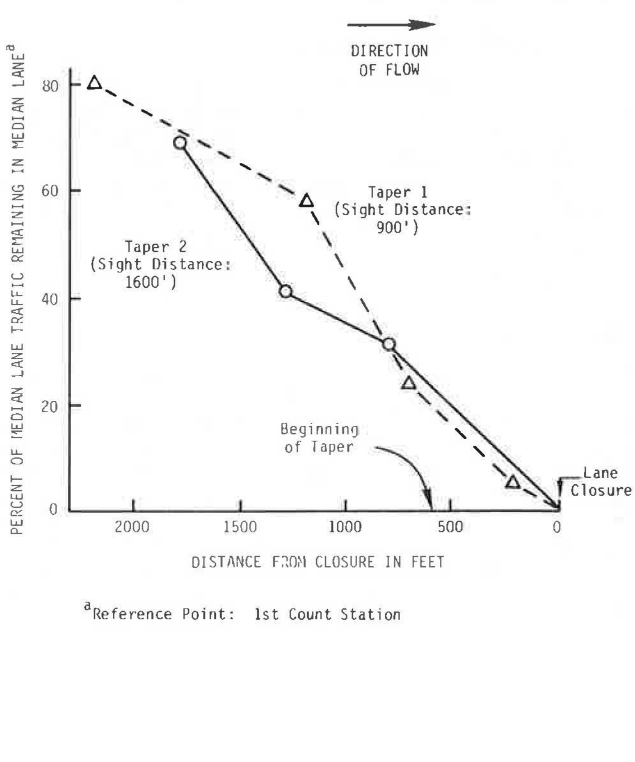
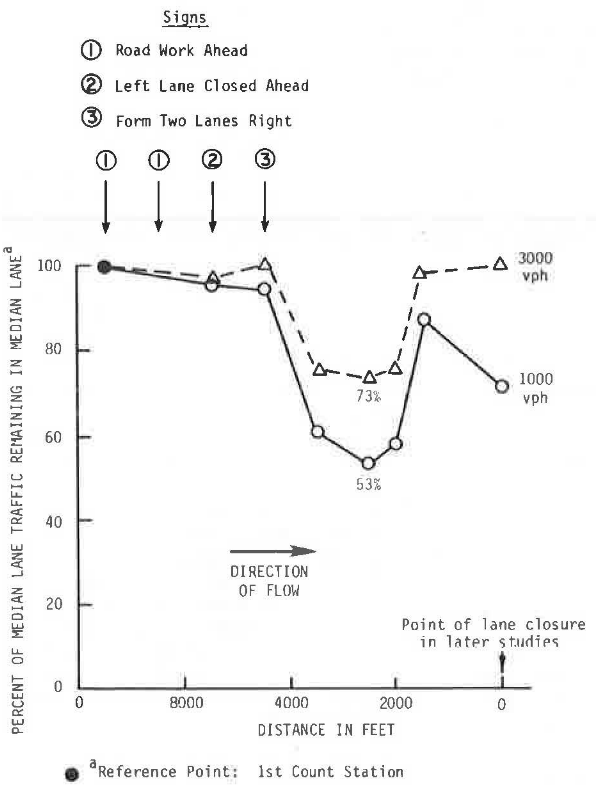


Figure 7. Effect of traffic volume on median-lane occupancy.



closed lane at the taper area. Thus, greater sight distances are desirable.

Traffic Volumes

Data were collected under the two volume conditions of 1000 and 3000 vehicles/h when only the advance signs were present. Figure 7 summarizes these data and reveals that traffic volume had a significant effect on driver response to the advance lane-closure signing. The figure shows that 47 percent (100 minus 53 percent) of the median-lane drivers changed lanes when the flow rate was 1000 vehicles/h. When the flow rate was 3000 vehicles/h, however, only 27 percent (100 minus 73 percent) changed lanes.

These numbers (47 versus 27 percent) suggest that as traffic volumes increase drivers are less likely to respond to advance signing for a lane closure. As volume increases, there are fewer available gaps in the traffic stream. Apparently, many drivers are unable or simply hesitant to find one of these infrequent gaps in order to merge out of a lane signed for closure.

The effects of traffic volume on median-lane occupancy in the taper area were also studied (sight distance to the lane closure = 1600 ft):

Traffic Volume (vehicles/h)	Median-Lane Traffic Still in Median Lane 200 ft Upstream of Cone Taper (%)
1000	17
3000	20

As the table indicates, 17 percent of the original median-lane traffic still occupied the median lane 200 ft from the taper when the flow rate was 1000 vehicles/h. As volume at the site increased to 3000 vehicles/h, the percentage of trapped vehicles increased to 20. The difference (17 versus 20 percent) is statistically significant at the 95 percent confidence level and suggests that, at the sight distances evaluated, traffic volume had an effect on driver response to the lane closure. More drivers were trapped as volumes increased.

Flashing Arrowboard

The effects of flashing arrowboards at the lane closure were also studied. The flashing arrowboard was positioned behind the cone taper in place of the static arrow sign (Figure 3). The use of the arrowboard at this site did not increase sight distance to the lane closure since the closure was purposely positioned just downstream of a hilltop. The arrowboard did, however, greatly enhance the conspicuity of the closure.

Figures 8 and 9 present the results of the arrowboard studies, showing the percentage of drivers remaining in the median lane versus distance from the lane closure for sight distances of 900 and 1600 ft, respectively. In the figures, the effects of the arrowboard are compared with those produced by the static arrow sign. Figure 8 indicates that the arrowboard had little added effect when the sight distance was only 900 ft. Traffic simply did not have time to respond, even though the arrowboard probably made the closure more conspicuous. The arrowboard did not have a significant effect when the sight distance was increased to 1600 ft, however. Figure 9 shows that 40 percent of the median-lane traffic still occupied the lane 1000 ft from the taper when the static arrow sign was used. When the arrowboard was used, this was reduced to only 23 percent. Thus, if sight distance is adequate at a lane-closure work zone (e.g., >1500 ft), the studies suggest that the use of an arrowboard encourages better driver response to the closure.

CONCLUSIONS AND RECOMMENDATIONS

Advance Signing

The field studies revealed that the advance signs normally used to warn drivers of freeway lane closures during maintenance operations are only partly effective in encouraging drivers to vacate the closed lane(s). The signs become less effective as traffic volumes increase.

Importance of Sight Distance

The field studies revealed that many drivers (20-50 percent, depending on volume conditions) wait until sighting the lane closure before attempting to merge out of the closed lane(s). Therefore, adequate sight distance to the lane closure must be provided to ensure safe and efficient traffic flow. As traffic volume increases, more and more drivers will be trapped at the lane closure if adequate sight distance is not provided.

Implementation

Based on the study results, it is recommended that a minimum sight distance of 1500 ft be provided at work-zone lane closures on urban freeways. If the sight distance is at least 1500 ft, the number of drivers trapped at the taper area will be minimized and thus safety and traffic flow will be enhanced. It is also recommended that an arrowboard, such as that shown in Figure 10, be positioned behind the cone taper at all freeway lane closures, regardless of sight distance, to help encourage traffic to merge out of the closed lane(s).

Figure 8. Effect of arrowboard when sight distance is 900 ft.

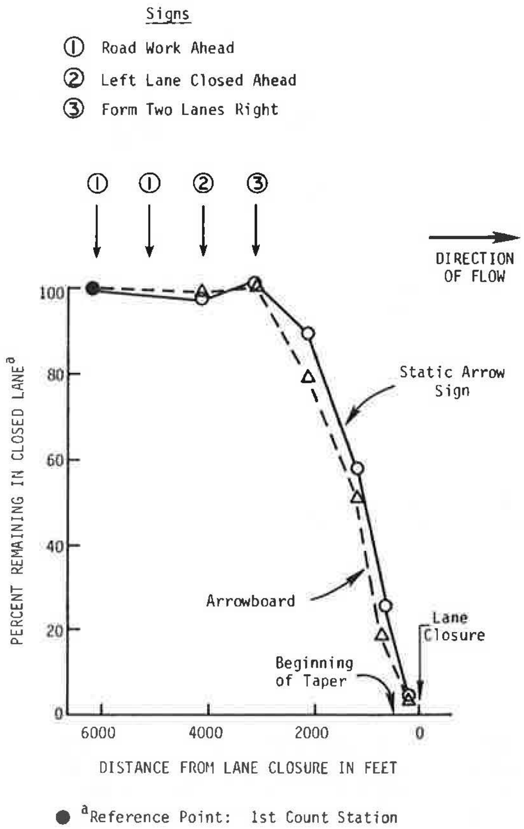


Figure 9. Effect of arrowboard when sight distance is 1600 ft.

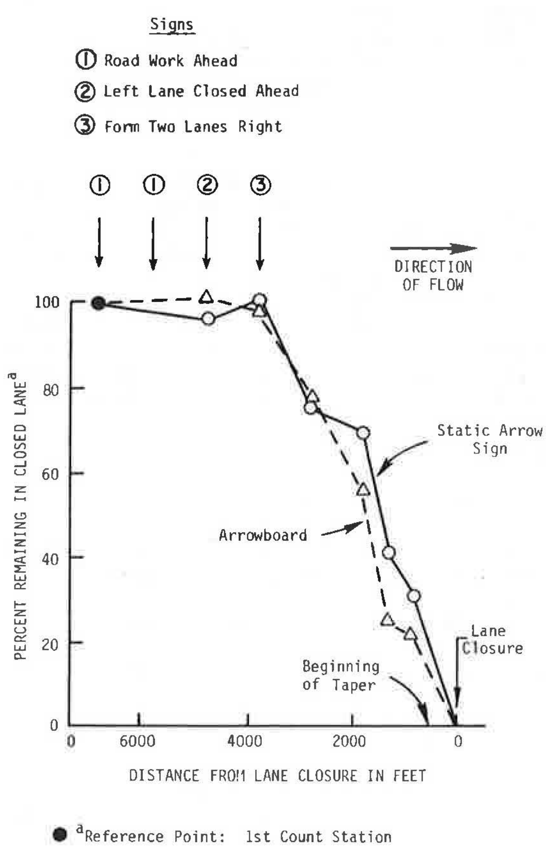


Figure 10. Typical arrowboard recommended for use at work-zone lane closures.

If it is not possible to provide a sight distance of at least 1500 ft, an additional arrowboard should be placed upstream of the cone taper for median and shoulder lane closures (1). This additional arrowboard should be positioned so that drivers are warned of the lane closure at least 1500 ft upstream of the cone taper. The advance arrowboard will encourage more drivers to vacate the closed lane before they see the closure itself. Even if an advance arrowboard is used, the sight distance to a lane closure should not be less than 1000 ft (absolute minimum).

Field Procedure for Checking Sight Distance

The following field procedure is recommended for checking sight distance to lane closures at work zones on urban freeways to ensure that a minimum sight distance of 1500 ft is provided.

Two vehicles are required to check sight distance (e.g., the job foreman's vehicle and the sign truck that is used to deploy traffic-control devices). Prior to installation of the lane-closure taper, the two vehicles stop together on the roadside or shoulder well upstream of the planned taper area. Driver 1 (sign truck driver) enters the roadway first and proceeds toward the taper area in the lane to be closed. As driver 1 pulls away, he or she begins counting lane stripes. After counting 38 stripes, driver 1 signals driver 2 to follow, either by radio or by flashing the vehicle lights. (A normal stripe-dash combination is 40 ft long; therefore, 38 stripes x 40 ft/stripe = 1520 ft.)

Driver 2 enters the roadway and follows driver 1, keeping the same approximate spacing (1500 ft). When driver 1 reaches the planned taper area, he or she pulls off the roadway. Driver 2 should be able to see vehicle 1 at the point where it pulls off the road. If so, it is likely that, once the lane is closed, sight distance to the closure will be 1500 ft or greater.

This procedure will give only a rough estimate of sight distance. After a lane is closed, the job foreman or another member of the work crew should drive through the work zone and check the sight distance to the lane closure. To do this, he or she drives in the closed lane and counts lane stripes from the point where the closure is sighted to the beginning of the taper. A minimum of 38 stripes should be counted to ensure that the minimum sight distance of 1500 ft is provided. If fewer stripes are counted, the taper should be relocated to provide greater sight distance or an advance warning arrowboard should be used at the site.

ACKNOWLEDGMENT

We wish to thank Hunter Garrison and Larry Galloway of TSDHPT District 12 for their assistance in conducting the controlled field studies. The cooperation and assistance provided by Districts 2, 15, 16, and 18 in conducting the preliminary studies are acknowledged. Tom Newbern, Herman Haenel, and Blair Marsden (D-18T) are also acknowledged for their constructive comments and suggestions during the course of the research.

The direction of the research was guided by a Technical Advisory Committee. The contributions of the committee members are gratefully acknowledged.

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Transit Bus Maintenance in Small and Medium-Sized Communities

GARY L. ROBERTS AND LESTER A. HOEL

The findings of a study of bus maintenance practices used by 13 small and medium-sized public transit systems in Virginia are presented. Bus maintenance activities are discussed according to two basic maintenance approaches: (a) municipal fleet, in which the buses in a fleet of all vehicles operated by a political jurisdiction are maintained, and (b) transit only, in which the transit buses of a publicly owned transit system are maintained. An overview of the current condition of bus maintenance is provided by comparing maintenance practices of the municipal-fleet and transit-only systems. The main factors that affect the performance of transit bus maintenance are identified and classified. These factors, such as inadequate personnel assignment and low maintenance priority for transit buses, serve as the basis for proposed guidelines to improve transit bus maintenance and to provide adequate protection of taxpayer investment statewide.

It is generally acknowledged that the maintenance of transit vehicles accounts for approximately 20 percent of total transit operating expenses (1) and, with the increasing complexity of the advanced-design buses (ADBs) currently being purchased, it is quite likely that this proportion will become even larger. The changing characteristics of the new buses were noted in a recent congressional report (2), which stated that "the ADB does not embody any serious attempt to simplify and make [buses] more durable, but rather may be another manifestation of our love affair with complex technology. Like new autos, new buses emphasize features related to style and comfort--often at the expense of durability, maintainability, and fuel economy."

In addition to facing the increased costs occasioned by the technical complexity of the ADB, transit bus systems are expected to lose the federal funds that they have come to rely heavily on for operating assistance. From its beginning in 1975, federal funding for operating assistance increased from $300 million to more than $1.1 billion in 1980. Because the costs of operating transit vehicles have increased significantly in the past two decades (1), this federal assistance is being used as a subsidy that enables transit fares to be kept artificially low (3,4). The loss of this subsidy will necessitate decreases in the operating budget, which will adversely affect bus maintenance.

When combined, this increasing technical complexity and decreasing federal operating assistance make a strong argument that the adequacy of transit bus maintenance in the future is uncertain. Thus, it is essential that the federal, state, and local agencies responsible for the administration and funding of public transit bus systems give high priority to efforts to assist the operating properties to increase the effectiveness and productivity of their vehicle maintenance.

The research reported here was undertaken to develop information that would be useful to state and local agencies in Virginia in developing and implementing the needed assistance programs.

OBJECTIVES AND SCOPE

The objectives of this research were (a) to document the current condition of transit bus maintenance and the maintenance practices used by the small and medium-sized transit systems in Virginia and (b) to propose guidelines for maintenance practices to improve transit bus maintenance statewide.

The small and medium-sized transit systems studied included all fixed-route transit bus systems except the Washington Metropolitan Area Transit Authority, which operates in Northern Virginia.

METHODOLOGY

The study comprised the following tasks:

1. A direct mail questionnaire survey of maintenance management personnel at 13 Virginia operating properties,
2. Site visits to each of these operating properties, and
3. An analysis of the information obtained from the survey and site visits.

QUESTIONNAIRE SURVEY

A questionnaire was mailed to maintenance management personnel at each of the 13 Virginia properties participating in the study to obtain information on maintenance facilities, personnel, procedures, problems, bus purchases, and cooperative efforts. All of the questionnaires were completed and returned.

Responses by Subject Area

As in any survey, the completeness of the responses varied but, in general, the range was good to excellent. The main responses in the six subject areas covered are discussed and summarized below.

Maintenance Facilities and Equipment

One maintenance facility was used for the support of transit bus operations at each of the properties. Several properties had various maintenance activities housed in different buildings but, since these were all located at the same site, they were considered to be one facility. The facilities ranged in age from 1 to 80 years, and the mean age was approximately 35 years.

The amount of maintenance equipment available was considered adequate by seven respondents and inadequate by the remaining six. The type of maintenance equipment available was judged adequate by five respondents and inadequate by eight.

Maintenance Personnel

The main responses concerning maintenance personnel relate to turnover, employment, and training. It was indicated that the annual turnover rate for maintenance personnel ranged from 0 to 10 percent, the mean being 2.6 percent. The turnover rate for service personnel was between 0 and 17 percent, and the mean was 2.4 percent. Twelve of the respondents, about 92 percent, indicated that it was difficult to attract qualified bus maintenance personnel, whereas one system did not experience such difficulty.

The respondents were unanimous in their expressed need for some sort of formal, in-state training programs for transit bus mechanics. Although the response to the relative need for training was unanimous, only 2 systems had an organized in-house training effort and 4 indicated that they had an in-house apprentice program.

Maintenance Procedures

Maintenance capability, contract work, vehicle records, maintenance schedules, and the levels of maintenance are the main categories included in maintenance procedures.

A total of 6 properties indicated that they had complete in-house maintenance capability, and 7 felt that their capability was less than complete. The need for more in-house capability was expressed by 8 of the respondents, whereas the other 5 felt that they did not need more capability.

A total of 4 of the respondents contracted out service work, and 5 contracted out maintenance. Component and subassembly rebuild work was the largest type of activity put out to contract. A total of 10 properties indicated that they did contract out rebuild work and only 3 did not.

All of the respondents indicated that they had a system of vehicle maintenance records of some kind; 3 of the systems responded that their records were computerized.

A preventive maintenance program was being used by 12 of the 13 properties and was based on vehicle use in miles. The indicated mileage interval used for the basic preventive maintenance schedule ranged from 1500 to 6000 miles; the mean for the 12 properties was approximately 3770 miles. In addition, 1 respondent indicated that certain maintenance procedures were scheduled on a seasonal basis.

The percentages of total maintenance reported to be preventive maintenance ranged from 20 to 80 percent, and the mean was 46.9 percent. The same figures also appeared for the percentages of maintenance work reported to be remedial: The range and the mean, 45.5 percent, were almost identical. The distribution, however, was quite different. In addition, routine component change-out and subassembly replacement were practiced by 3 properties.

Of the 10 maintenance tasks listed in the questionnaire, 5 were commonly done by all respondents. The scheduled inspection of vehicles and the repair of major components were being done by 12 properties. Of the 5 most common tasks--minor repairs and replacement, replacement of parts, and replacement of major components--3 were being done by all respondents.

The 5 remaining tasks were being performed by a smaller number of the respondents. The rebuilding of major components and the repair of subassemblies were being done by 7 properties. A total of 9 properties reported that they replaced subassemblies, and only 5 rebuilt subassemblies for stock. The final maintenance task, body and chassis structural work, was being done by 8 properties.

The reporting of defects was the last subject covered in the questions on maintenance procedures. A total of 10 respondents indicated that vehicle operators reported vehicle defects to maintenance personnel on a written form, 2 indicated that they used verbal reporting, and 1 had no set procedure. Vehicle service personnel in 8 properties used a written form to report defects to maintenance personnel, 3 properties reported these verbally, and 2 had no set procedure.

Maintenance Problems

Most of the maintenance problems cited by the respondents related to the kind of operation and the type of vehicle. Of the responding properties, 6 indicated that they experienced maintenance problems peculiar to their operations. These included a very short service life for brake linings and tires caused by hilly terrain. Transmission failures, and the attendant road calls, were also attributed to the terrain over which the properties' vehicles operated. Various problems resulting from inadequate maintenance facilities and equipment were cited. Several properties cited problems with limited manpower and mechanical ability as being related to their kind of operation.

A much larger group, 10 respondents, noted problems experienced as a direct result of the type of transit vehicle they were operating. These responses indicated substantial problems with vehicles that were no longer being marketed in the United States and vehicles for which major components and subassemblies were no longer available from the manufacturer. Certain foreign-manufactured buses were singled out as a major source of problems, along with small-sized domestic vehicles that were not holding up very well in daily revenue service.

An additional major source of problems was the high rate of component and system failures experienced in the operation of ADBs, irrespective of the bus manufacturer. Specifically cited were failures of air-conditioning equipment, electrical components, brake systems, wiring, engine accessories, and automatic transmissions. It appears that failures were found in all of the major systems necessary for the operation of the bus. These failures were noted to have led to numerous running repairs and in-service breakdowns, which had resulted in costly road calls.

Bus Purchases

A total of 10 properties said that they expected to purchase new buses within 3 years. The numbers of buses to be purchased ranged from 1 to 47 and totaled 118.

Of the respondents, 11 felt that the buses available were compatible with present maintenance operations. A smaller number, 7 respondents, felt that the bus manufacturers were providing adequate technical assistance.

Questions relating to spare buses were also included in this section of the questionnaire. The percentages of total bus fleets indicated as spares by the respondents ranged from 9 to 40 percent, and the mean value was approximately 20 percent. A total of 9 respondents felt that a certain percentage of the fleet should be spares; their figures ranged from 15 to 40 percent, and the mean was approximately 25 percent. The other 4 properties related the number of spares to the size and type of operation, maintenance capability, etc., and not to some percentage of the fleet alone.

In responding to a related question in this area, seven of the operations said that they leased their tires and the others said they purchased them.

Cooperative Effort

The questions under the heading "cooperative effort" contained the term "statewide cooperative". The definition of this term in the questionnaire was open-ended in order to gain information concerning the concept of these cooperative approaches rather than information on any particular program.

The cooperative purchase of parts and supplies for bus maintenance was believed to be a possible asset by 6 of the properties, and the cooperative rebuilding of components and subassemblies was seen as an asset by 7. The greatest positive response was registered for the idea of cooperative bus purchase: 8 properties felt that this would be an asset.

The aggregate results presented in this section contained responses for both small and medium-sized public transit systems. Small systems were those with fewer than 20 buses, and medium-sized systems were those with more than 20 buses but fewer than 250. Taking part in the study were 7 small systems and 6 medium-sized systems. These two groups were separated by their own distinctive approaches to bus maintenance. The only exception to this was a small system that used the maintenance approach associated with the medium-sized systems.

Thus far, no attempt has been made to separate the results by group; however, that will be done on the basis of maintenance approach in the next section of this paper. When this is done, the differences and the common problems shared by both the small and medium-sized transit systems are illustrated. The results for individual systems are not indicated or discussed so that there can be no attempt to compare one system with another.

Summary of Responses

The analysis of the questionnaire results produced a comparative interpretation of the two basic maintenance approaches used in Virginia: (a) the maintenance of transit buses as a part of the fleet of all vehicles owned by a political jurisdiction and (b) the maintenance of transit buses only, in the case of a publicly owned transit system. These two approaches are referred to in this paper as "municipal fleet" and "transit only". It must be stressed that the interpretation represents the groups as a whole and that comparisons of individual transit systems were not appropriate. The lists presented below characterize the conditions of each group separately and those that were generic to both groups.

Municipal Fleet

The municipal-fleet approach had the following characteristics:

1. The systems had inadequate amounts and types of maintenance equipment.
2. The turnover rate for service personnel was higher than the rate for maintenance personnel.
3. Written maintenance procedures were not in common use.
4. The average preventive maintenance inspection interval was approximately 2900 bus miles.
5. Major component rebuilding in-house was not a common practice.
6. The replacement of subassemblies in-house was not a common practice.
7. Subassemblies were not rebuilt in-house.
8. Body and chassis structural repairs generally were not done in-house.
9. Written operator reports of bus defects were not in common use.
10. Written service personnel reports of bus defects were not in common use.
11. The type of transit operation caused maintenance problems.
12. Spare buses, on the average, constituted 30 percent of the fleet.
13. Bus tires were purchased.
14. Interest in all the cooperative approaches was common.

Transit Only

The characteristics of the transit-only approach were as follows:

1. The turnover rate for maintenance personnel was higher than the rate for service personnel.
2. Written maintenance procedures were in common use.
3. The average preventive maintenance inspection interval was approximately 4800 bus miles.
4. Major component rebuilding in-house was a common practice.
5. The replacement of subassemblies in-house was a common practice.
6. Subassembly rebuilding in-house was a common practice.
7. Body and chassis structural repairs were generally done in-house.
8. Operator reports of bus defects were in written form.
9. Written service-personnel reports of bus defects were in common use.
10. Spare buses, on the average, made up 18 percent of the fleet.
11. Bus tires were leased.
12. Interest in possible cooperative approaches was not common.

Generic

Characteristics shared by both municipal-fleet and transit-only maintenance approaches were as follows:

1. The overall turnover rate for personnel was low.
2. It was difficult to hire qualified maintenance personnel.

3. The maintenance personnel needed additional training.
4. An increase of in-house maintenance capability was needed.
5. Contracting out maintenance tasks was a common practice.
6. The use of computer technology to support the maintenance function was very limited.
7. Preventive maintenance was a common practice.
8. Preventive maintenance schedules were based on bus mileage.
9. Periodic maintenance was not a common practice.
10. The type of bus used caused maintenance problems.
11. There were plans to purchase new buses within 3 years.
12. The maintenance operation was compatible with current buses.
13. The systems were unhappy with bus manufacturers' approach to technical support for the customer.

SITE VISITS

Site visits were made after the questionnaires had been returned so that survey responses could be discussed and clarified, if necessary, during the visits. Information was obtained on maintenance facilities, equipment, practices and contracted functions, personnel, organization, information systems, and planning.

The information obtained during the site visits is summarized below in two parts corresponding to the two basic approaches to vehicle maintenance--municipal fleet and transit only--discussed above.

Municipal Fleet

Transit systems in the municipal-fleet category ranged in size from 3 to 11 buses, and all operated fixed-route and scheduled service. The general findings from the visits to the municipal-fleet systems are reflected in the list below. Not all of these characteristics apply to all of the municipal-fleet operations; however, all are negative factors that diminish maintenance productivity.

1. The facility was undersized.
2. The facility was improperly equipped.
3. The maintenance operation was incorrectly staffed.
4. The employees were in need of initial or additional training.
5. Maintenance priority practices did not favor transit vehicles.
6. Breakdown maintenance was given priority over preventive maintenance.
7. There was a lack of goals and objectives for maintenance operations.
8. There was a lack of locally developed and implemented performance indicators.
9. Data collection and analysis were not sufficient for monitoring performance and increasing productivity.
10. There was a lack of maintenance planning.

Transit Only

Transit systems in the transit-only category ranged in size from 11 to 212 buses, and all operated fixed-route and scheduled service. The general information gathered during site visits to the transit-only systems is the basis for the descriptive list presented below. As in the case of the municipal fleets, not all of these characteristics apply to all of the transit-only operations.

1. The maintenance employees were in need of initial or additional training.
2. There was a general lack of goals and objectives for maintenance operations.
3. There was a general lack of locally developed and implemented performance indicators.
4. Data collection and analysis were insufficient for monitoring the performance of maintenance and increasing productivity.
5. There was insufficient planning of maintenance.

Summary

Compared with the maintenance facilities of the municipal fleets, those of the transit-only systems were much better organized and laid out, had more room for access to all areas of the vehicle, and were much better equipped.

The maintenance practices used by the municipal fleets were fewer in number and approached at a lower level than those used by the transit-only systems. Neither group engaged in periodic maintenance to any appreciable degree.

Systems in the transit-only group had a cadre of transit bus maintenance personnel whereas the municipal fleets had only vehicle maintenance personnel. Maintenance training and retraining were needed in all systems, and their importance was increasing daily.

Bus maintenance had a low priority in the municipal fleets, established by both formal design and informal practice. In the transit-only systems there was no problem with maintenance priority since only buses were maintained.

There was very limited use of modern methods of data collection and analysis in the maintenance operations of the municipal fleets. In addition, these systems had no goals and objectives, either written or verbally expressed. The collection and analysis of data for use in the maintenance operation were more common practices in the transit-only systems; however, there was comparatively little use of modern methods such as computer support. There was also a general lack of goals and objectives for maintenance functions in the transit-only systems.

Maintenance planning depends on proper data collection and analysis. As previously discussed, these practices were not well organized or used to any appreciable degree. The result was that maintenance planning was virtually nonexistent in the municipal fleets and only crudely practiced in most of the transit-only systems.

CONCLUSIONS AND RECOMMENDATIONS

When combined, the questionnaire responses and the information from the site visits provided a picture of transit bus maintenance at small and medium-sized systems in Virginia.

In the municipal fleets, maintenance practices were unorganized and informal. Maintenance was provided for the transit buses as an adjunct function and was perceived as carrying a lower priority than the other maintenance activities. There was no formulation of policy for maintenance operations, and complete control was vested in some unit of the local government.

The commitment to proper bus maintenance was much stronger in the transit-only systems. Overall, these systems were better organized and administered and were staffed by personnel who were knowledgeable about transit buses and the complications of proper maintenance. It is evident from the information

Table 1. Type and number of transit systems affected by various maintenance factors.

Factor	No. of Systems Affected		
	Municipal Fleet	Transit Only	Generic
Lack of goals and objectives	6	6	12
Inadequate maintenance personnel assignment	4		
Inability to hire qualified personnel	6	7	13
Lack of maintenance personnel training	6	6	12
Low maintenance priority for transit buses	4		
Inadequate maintenance facility capability	3	2	5
High incidence of running repairs and road calls	3	4	7
Lack of data collection and analysis	6	6	12
Lack of maintenance system planning	6	7	13
Lack of periodic maintenance programs	6	5	11
Inadequate preventive maintenance programs	6	6	12
Need to educate local political bodies	6	7	13
Present conditions of buses	3	4	7
Use of inadequate buses	3	1	4
Use of obsolete buses	4	1	5
Complex design of ADBs		3	
Skill level to maintain ADBs		3	
Lack of bus maintenance operational expertise	6		
Inadequate number of spare buses	2	3	5

presented here that transit bus maintenance is complex and in need of improvement at all the systems reviewed. This complexity is the result of relations among the many factors that have an influence on the maintenance function. These factors are identified in the next section of this paper.

Factors That Affect Maintenance Performance

The questionnaire results, when combined with the observations and information obtained during the site visits, provided a data base that was analyzed to identify and classify factors that affect the productivity of transit bus maintenance. Numerous factors affect the maintenance of transit buses, and they vary enormously from system to system. It would have been a monumental undertaking to identify, categorize, and discuss all of the probable factors that were affecting the maintenance operations in each of the 13 Virginia systems reviewed. What were identified were the main factors, within which a multitude of smaller factors are found.

The identified factors were further classified by group as municipal fleet, transit only, or generic to both groups. Classification of a factor as generic or otherwise does not mean that the factor affects all the systems of that group. The factors, the system category to which they apply, and the number of systems they affect are given in Table 1.

A majority of these main factors (14) were classified as generic, and these as a whole tend to be more complex and consequential than the others, which is to be expected. The 5 remaining factors identified were specific to the municipal-fleet or transit-only systems.

Proposed Maintenance Guidelines

Until the present time, there has been no attempt by federal or state government to review the maintenance of transit equipment purchased with grant funds. There is no accountability for these funds that ensures that the equipment will receive the best possible maintenance and thus provide maximum service to the public.

The various factors that affect the performance of transit vehicle maintenance have been presented. It is evident from the material discussed in this paper that the operating properties cannot be held entirely responsible for the current situation in transit vehicle maintenance. The proposed federal approach to the problem is a program of mandatory maintenance for transit vehicles purchased with capital grant funds (5). A federal mandate for vehicle maintenance will not upgrade the performance of maintenance unless the factors that affect maintenance are addressed and relief in those areas is provided to transit maintenance operations.

The maintenance guidelines proposed here are meant to be applied at the state level to all operating properties that receive state funds. They will provide the necessary protection for the already considerable capital investment in transit in Virginia and continuing insurance for future investments.

This approach places the burden of compliance on the operators, but at the same time it provides them with the tools necessary to meet that responsibility in such a way as to allow the guidelines to be fashioned to local conditions. The enormous variations in local operating conditions in Virginia make this type of approach essential.

The proposed guidelines do not dictate the type of maintenance activities to be carried out. A total of 13 transit operations were reviewed in this study, and all operated under different geographic conditions, used different types of equipment, and had that equipment maintained by mechanics of varying skills. For these reasons, it is impossible to propose a maintenance approach for inspection schedules or component replacements that would be correct for more than one operation.

The proposed guidelines are stated in general terms and deal with the organizational and administrative approaches to maintenance, not with the particular maintenance procedures or the activities they encompass. The wording is general to provide the flexibility necessary for implementation of the guidelines. The goal of the proposed guidelines is not standard vehicle maintenance but a standard approach that will become familiar to each of the transit properties. These guidelines will promote an exchange of information and a mutual understanding of the operational aspects of transit vehicle maintenance as practiced by properties in Virginia.

The following maintenance guidelines are proposed:

1. Formulation of specific goals and objectives targeted at the vehicle maintenance function and based on local operating conditions;
2. Implementation of an organized and systematic preventive maintenance program to include operator inspection, daily service inspections, and scheduled maintenance inspections;
3. Use of maintenance information forms that include, as a minimum, (a) operator inspection (vehicle defect) forms, (b) detailed maintenance inspection forms designed for the transit vehicle being inspected, (c) road call and emergency maintenance forms, (d) detailed daily fuel, oil, and fluid use form, and (e) maintenance work order (repair order) form;
4. Systematic data collection and analysis to support the formulation and implementation of appropriate maintenance performance indicators and measures, including, as a minimum, data on (a) maintenance performed (type, mileage, and description), (b) actual labor time for inspection, repair, and rebuilding, (c) parts used and cost for inspection, repair, and rebuilding, (d) component and subassembly replacements (new, rebuilt, or used replacements), (e) road calls (cause, action taken, labor time, time out of service, parts, and resolution), (f) number of missed or late runs due to maintenance problems, (g) materials and supplies consumed per vehicle, (h) number of buses out of service, for

what reason, and how long, and (i) other data necessary due to local operating conditions;

5. Systematic maintenance planning for preventive and periodic maintenance based on the data collection and analysis proposed in guideline 4;

6. Specific maintenance personnel assigned to inspection and repair of transit vehicles; and

7. Minimum training requirements and competency qualification for maintenance personnel.

Clearly, in light of the present economic conditions in public transit, the proposed guidelines must be accompanied by the proper direction and level of assistance from the appropriate local and state agencies. Guidelines 2, 3, 4, and 6 can be implemented by the operating properties with minimal disruption and outside assistance. The remaining three guidelines--1, 5, and 7--will require a certain amount of assistance for implementation. Such an effort is now being undertaken as an extension of this research by the Public Transportation Division (PTD) of the Virginia Department of Highways and Transportation. The implementation of guideline 1 will be assisted by the current actions of PTD, in conjunction with the Virginia Association of Public Transportation Officials, to develop a transit information exchange program and management seminar series at the state level to deal with maintenance. Guideline 5 is being supported by the efforts of PTD to initiate a vehicle maintenance management information system study effort and demonstration program at a medium-sized property. Once developed and implemented, this system will be made available to the other transit operations within the state. Finally, guideline 7 is being supported by the ongoing efforts PTD is sponsoring to define and refine the possible alternatives for providing training assistance programs in transit bus maintenance to all Virginia operating properties. These actions will give the transit operators the assistance they need to combat external factors that affect maintenance performance and provide accountability for capital funding grants.

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Louisiana's Equipment Replacement Dilemma

G.L. RAY

The Louisiana Department of Transportation and Development is currently in the second year of a three-year equipment improvement program. The Legislature approved the program based on an economic analysis that indicated that a 20 percent annual savings was possible. Net savings will accrue after a four-year period as a result of increasing capital investment to reduce the cost of equipment operations, assuming the economic predictions are used. An accumulated unit cost curve is maintained on each individual machine and, along with repair limits, is used to identify the critical repair that makes an equipment unit uneconomical. This critical repair concept is the basis for identifying the optimum time to replace each unit. The method has accurately predicted the optimum replacement point in 96 percent of the cases and allows for ranking of replacement needs in priority order so that available funds can be used most effectively. Although this concept is economically sound, there are many obstacles in the path to implementation. Implementation has been difficult at the field level because of the dilemma surrounding replacement decisions. Since an average one-year lead time is required to obtain new equipment, replacement equipment is not normally available at the time of failure. Managers are rarely able to retire a unit and await replacement. This dilemma is compounded by the buildup of a replacement backlog over a period of many years. Of a 7500-unit equipment fleet, almost 3500 units are beyond the economic replacement point, which further complicates the manager's dilemma. For this program to succeed, the field manager must thoroughly understand the dilemma posed by the replacement decision and be willing to support the computer-assisted projections based on faith in the statistical accuracy of the system.

In Louisiana, management control of the equipment fleet of the Louisiana Department of Transportation and Development is exercised by the Division of Maintenance and Field Operations. Central control of the statewide fleet is the responsibility of the director of maintenance and field operations, who delegates routine decisionmaking authority to the chief maintenance and operations engineer. Service facilities are located in nine Department of Transportation and Development districts under the direction of a district administrator. Planning, budgeting, systems development, experimental programs, and other centralized functions are directed by the maintenance systems engineer, who reports to the chief maintenance and operations engineer. Equipment acquisition, disposal, specification development, replacement control, and budget control are performed by the equipment engineer, who reports to the maintenance systems engineer. Parts are supplied by contractor-operated parts stores located in each major repair facility. Equipment is assigned to an individual or an organizational unit, and cost is distributed via a rental rate as use is reported. New equipment is purchased through a central fund controlled by the equipment engineer. All replacement funds are budgeted centrally by using projected needs identified by the equipment management system. Zero-based budgeting techniques are used to evaluate budget alternatives and communicate these alternatives to the Legislature.

REPLACEMENT COSTS

Equipment costs can be subdivided into two general groups: fixed costs and variable costs. Variable costs can be further subdivided into those costs that are proportional to use and those costs that compound with use. Variable costs that are proportional to use should not affect the replacement decision if the challenging machine can be expected to experience similar costs (1). Expenditures for tires, tubes, batteries, blades, fuel, and lubricants are examples. Costs that influence the replacement decision are those costs that compound with use, such as repair parts, repair labor, contract work, and reliability costs. Fixed costs are incurred regardless of the amount of use. Depreciation has a fixed-cost component and a variable-cost component but tends to be predominantly fixed. Depreciation was considered a fixed cost for this analysis because a variable-cost relation could not be established for many types of equipment. These categories of expenditures are used in the replacement model described in this paper.

Reliability costs require additional explanation. As a machine ages and repairs become more frequent, one expects downtime to increase. If downtime costs can be adequately defined and measured, the loss of a machine's reliability as it ages can be included in the replacement analysis. Downtime in the field is extremely difficult to measure and account for because equipment-related delays do not necessarily cause delays to planned maintenance activities. The disruptive effect of equipment downtime can often be countered by supervisor action, including preplanning of alternative activities, use of substitute equipment, and use of alternative procedures. Downtime in the shop, however, can be accurately measured and a cost penalty applied for inclusion in the replacement analysis. If it can be assumed that enough second-line units are available to mitigate the effect of downtime, the cost of shop downtime becomes defined by the cost of maintaining second-line equipment. This is the procedure used in Louisiana to inject this consideration into the replacement analysis.

The cost of depreciation also requires some elaboration. Many different depreciation formulations are used by industry. These formulations are usually selected based on the tax strategy of the individual organization. Because a government agency does not have a tax strategy to consider, it was felt that a depreciation schedule that predicted actual cash value should be the method of choice. Actual cash value was determined by studying various "blue books" and guides that reflect market trends. Once a depreciation curve was constructed for each equipment type, this curve was compared with the results of departmental auctions. Since these results are only available for the latter portion of a machine's life, the relation derived from market studies was forced through the average sales point to describe a curve that would approximately predict actual cash value to the Department. Once depreciation was determined in this manner, these costs, along with the costs outlined above, were used to develop a replacement methodology.

REPLACEMENT METHODOLOGY

Since all replacement models require assumptions about the future, the perfect replacement formulation has not yet been devised. Considerable effort has been expended to establish a practical replacement criterion for departmental equipment that effectively weighs the economics of replacement. Initially, the work focused on the evaluation of different replacement concepts. Two basic approaches were studied from the viewpoint of simplicity and accuracy: a group replacement policy and an individual replacement policy. An individual evaluation of equipment resulted in a projection of minimum cost that was more accurate than a group evaluation by a factor of approximately 19 percent. This factor was developed by simulating the use of various replacement criteria on a sample of wheel tractors that had been retained longer than 15 years. The sample average minimum cost was computed and used to evaluate each simulated policy. The group replacement policy produced a minimum cost that was 19 percent greater than the minimum cost produced by the best individual replacement policy. A simple criterion for replacement was also found to be as effective as more complicated models in view of the economic parameters facing the Department (2).

The accumulated unit cost criterion described in several textbooks on replacement theory proved to be an effective method of dealing with a wide variety of equipment types (3). Accumulated unit cost curves were computed by dividing the lifetime sum of those costs known to compound with use by the lifetime summed use and monitoring this computation annually. This concept provided a simple technique for individually evaluating each equipment unit. The accumulated unit cost curve also allowed for predicting repair limits simply by projecting the following year's use. The selected replacement criterion is shown in Figures 1 and 2, which depict a series of accumulated cost curves for a continuing chain of like replacements. The theory is explained by two alternatives, A and B. Alternative A, replacement at the actual minimum cost point, results in three replacements over 6000 h of use at points A1, A2, and A3. Alternative B, replacement after the actual minimum cost point, results in two replacements over 6000 h of use at points B1 and B2. The accumulated unit cost of alternative A, TA, is \$1.31/h. The accumulated unit cost of alternative B, TB, is \$1.32/h. It can be seen from Figures 1 and 2 that minimum total cost for a continuing chain of replacements occurs at the minimum accumulated unit cost for each machine.

At the completion of the conceptual design phase, three basic assumptions were made: (a) Interest and inflation would be considered at the fleet level, (b) the "challenging" machine would have essentially the same cost pattern as the "defending" machine, and (c) technical obsolescence is insignificant in most instances. In practice, interest is irrelevant at the individual unit level because the objective of the analysis is to minimize the total cost of equipment operation. A present-cash-flow analysis is used in Louisiana at the equipment unit level and has proved to be simple, effective, and easily understood. Since inflation and interest tend to be

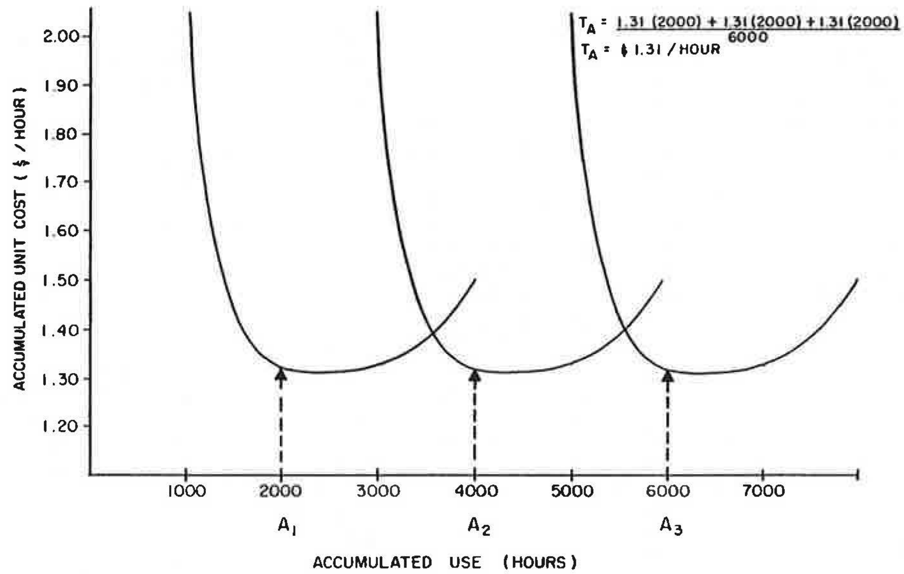

Figure 1. Accumulated unit cost replacement model, alternative A: replacement at minimum cost point.

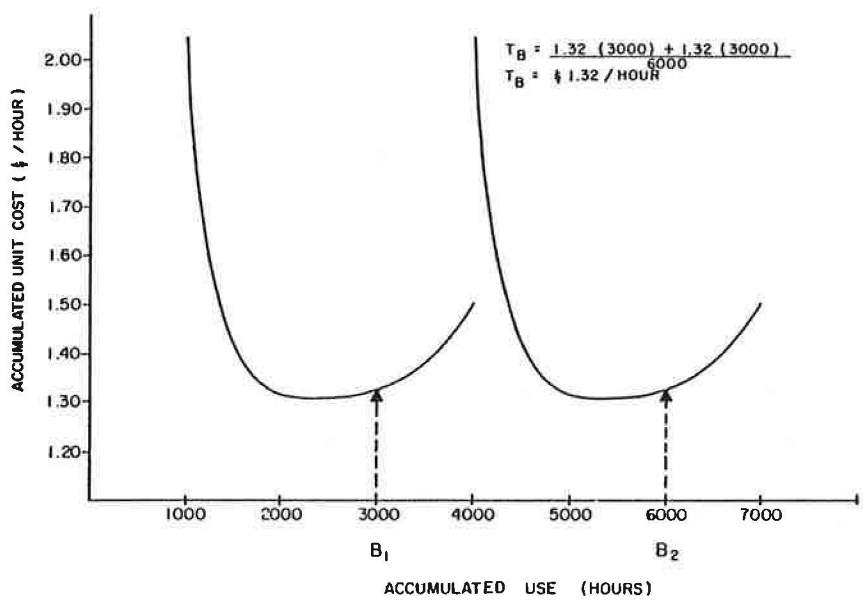

Figure 2. Accumulated unit cost replacement model, alternative B: replacement after minimum cost point.

additive factors, inflation is usually considered in the selection of an interest rate. Inflation is predictable from historical trends and has been included throughout this paper. If an appropriate interest rate can be determined, it will be included at the fleet level. The assumption that the challenging machine will have a cost pattern similar to that of the defending machine (disregarding technical obsolescence) is as good as any other assumption that involves events five or more years in the future. In practice, cost curves are extremely variable between successive replacements and this variance cannot be predicted with certainty. The cost pattern is consistent, however, in that a single minimum point is usually observed over the life of the unit. Technical obsolescence is a significant factor in the electronics industry, but dump trucks and construction equipment are not developing as rapidly. There are exceptions, but they can easily be handled as the need arises. When technical obsolescence was an issue, a complete reevaluation of an entire activity was required rather than a simple comparison of equipment alternatives.

The principal weakness of the accumulated cost method was that the minimum cost point had to be exceeded before it could be identified. Repair limits helped to solve this problem (4, p. 337). Repair limits allow one to evaluate the replacement decision at any time prior to the minimum cost point by defining the annual cost that would cause the accumulated cost curve to reach its minimum juncture. The following equation was used to compute repair limits:

$$\text{Annual repair limit} = (\text{lifetime accumulated cost rate} \times \text{projected annual use}) - \text{projected annual depreciation} \quad (1)$$

Once repair limits were determined for each unit, equipment could be evaluated at the time of each repair to determine whether the repair could economically be made. This allowed for evaluation of replacement prior to a significant repair expenditure.

Since the Department could not fund the capital outlay requirements identified by the equipment management system without first developing a capital budget program, some method of priority of replacement had to be devised in order to make good decisions concerning the best use of scarce replacement funds. To accomplish this, the cost of having failed to replace at the optimum point was termed the retention cost. Retention cost is computed by subtracting the minimum cost rate from the current cost rate and multiplying the result by the accumulated use. The retention cost represents the total cost of having kept the unit from the minimum cost point to the present. This may be thought of as the cost error that results from having failed to replace at the optimum point. The fleet objective was to minimize the error--i.e., the retention cost--within the limits of replacement funds. A ratio of retention cost to predicted replacement cost was used to establish replacement priority. The higher ratio indicated a greater reduction of retention cost per available capital outlay dollar and placed that unit at a higher priority rank in relation to other units. Table 1 illustrates the priority disposal listing, which identifies units with similar replacement priority.

EVALUATION OF REPLACEMENT METHODOLOGY

In order to evaluate this system, a feedback measurement was required along with a performance standard. FY 1974 data were used to evaluate the accuracy of the selected replacement criterion and the effectiveness of current procedures on a fleetwide basis. Table 2 summarizes the pertinent information. The accuracy of the replacement model was measured by the error frequency. This was the number of times an equipment unit failed to produce a single universal minimum cost similar to that shown in Figures 1 and 2. Out of 2133 cases, this occurred in 91 instances, or 4 percent of the time. The cost error was even less than 4 percent because the cost curve tends to be relatively insensitive in the area of the minimum. Individual units were analyzed from the 91 errors found, and many of these errors were determined to result from severely curtailed patterns of use near the end of depreciated life. It was concluded that the selected model was a good approximation to an economic fleet replacement criterion. The accumulated equipment cost curve did, in fact, produce a universal minimum in the vast majority of cases. The idea that a recent high repair cost dictates retention of the unit until the repair cost is "recovered" is invalid 96 percent of the time if the minimum point has been reached.

Replacement or disposal of equipment should reduce the cost of routine equipment operations. Since current procedures could be evaluated by looking at cost errors due to improper replacement timing, the individual equipment cost curve was used to evaluate all active equipment. When an individual cost curve was increasing, the minimum point was obtained and the cost of having failed to replace at the minimum point was computed. The minimum point cannot be determined 100 percent of the time, but evaluation of the error could serve as a yardstick for comparison of present practice with alternative approaches. From Table 2, 35 percent of the listed equipment was replaced in FY 1974 but only 12 percent of the cost error was eliminated. These statistics indicate that an improved replacement model could result in considerable savings to the Department.

Some appreciation of the effectiveness of the replacement analysis can also be gained by studying Table 3. The FY 1979 cost of equipment identified for replacement in FY 1978 but retained due to inadequate replacement funding is given in relation to the cost of all other units. The retained units identified for replacement in 1978 amount to 35 percent of active units in 1979 but account for 56 percent of the repair parts costs and 59 percent of the downtime costs.

LOUISIANA'S CURRENT REPLACEMENT POLICY

In 1978, a departmentwide equipment management policy was published. The following points illustrate the principal objectives of this policy:

1. Departmental policy was defined as "to replace equipment on an economically sound basis."
2. The disposal list produced by the equipment management system would serve as the principal vehicle for identification of end of economic service life.
3. The district administrator or section head would ensure that all equipment on the list was reviewed and equipment that would no longer be replaced was deleted. Equipment remaining on this list would be placed on order.
4. As new equipment was received, the highest-priority unit of that type would be replaced. If the district administrator or section head felt that the analysis was in error, he or she could challenge the analysis by providing correct information or improved data (repair estimates).

This policy was an attempt to focus management attention on the facts and figures related to equipment replacement rather than rely on a totally subjective analysis. Although this policy is still in effect, the dilemma surrounding the replacement decision has resulted in marginal implementation.

REPLACEMENT DECISION

As previously noted, the replacement decision must be made when technical improvements dictate the acquisition of new equipment or when old equipment fails due to declining performance or excessive maintenance. Historically, technical evolution of most transportation maintenance equipment has been slow and deliberate; thus, technical obsolescence should be evaluated case by case. Replacement under conditions of declining performance and/or excessive maintenance was deemed worthy of analysis by computer-oriented processes so that timely decisions could be made.

Computer repair limits normally provide the first decision point related to replacement or retirement of a unit. Significant repair estimates cause shop personnel to consult repair-limit listings or computer terminals at district offices to determine whether limits are being exceeded. Once it has been determined that the proposed repair will exceed the established limit, several factors must be considered. Operational commitments will often mandate that the repair be performed regardless of economic considerations. Excessive acquisition lag time may also dictate a decision to repair. Ideally, the decision to repair a unit that is expected to exceed the repair limit should be reviewed fleetwide so that statewide priorities can be reconsidered.

Tables 4 and 5 compare units that were evaluated in FY 1981 based on current condition with units on the disposal list. The results show that the challenger units effectively displaced the defending units, assumed a higher priority on the disposal list, and were retired from operation. This evaluation normally takes place when new equipment is

Table 1. FY 1981 equipment priority disposal listing.

			Age (years)		Rate		Cost ($)	
Rank	Equipment No.	Description	Current	Minimum	Current	Minimum	Retention	Replacement
366	130-343	Pickup	7	4	0.068	0.026	5 223	6 874
367	231-708	Sickle bar mower	6	3	7.974	5.035	6 686	8 803
368	262-107	Wheel tractor	15	7	1.867	0.384	7 551	9 944
369	130-035	Pickup	6	4	0.159	0.089	5 209	6 874
370	233-533	Slope mower (5 ft)	7	4	7.420	4.043	10 506	13 896
371	266-252	Backhoe/loader	11	8	17.236	5.420	14 664	19 398
		Dump truck						
372	140-818	Light	6	3	2.479	1.209	7 821	10 399
373	150-301	Medium	6	3	1.828	0.846	7 820	10 399
374	150-216	Medium	9	4	1.258	0.613	7 810	10 399

Table 2. FY 1974 equipment replacement analysis.

Equipment Series	No. of Units Requiring Disposal	Error Frequency	No. of Listed Units Actually Disposed Of	Retention Cost Reduction ($)	No. of Units Ordered	Potential Retention Cost Reduction ($)
Passenger	470	24	90	38 916.37	361	177 297.57
Hauling	599	16	115	83 518.62	180	486 431.49
Processing	260	15	8	6 568.92	24	242 827.23
Earthwork	180	5	11	33 238.73	21	473 165.04
Mowing	624	31	59	67 495.15	166	604 007.93
Total	2133	91	283	229 737.79	752	1 983 729.26

Note: Number replaced = 752/2133 = 35 percent; cost reduction = $229 738/$1 983 729 = 12 percent; expected error = 91/2133 = 4 percent.

Table 3. Evaluation of equipment replacement prediction.

	Continued Economic Operation Predicted in FY 1978			Replacement or Disposal Predicted in FY 1978			Replacement Predicted Versus Total (%)		
District	Parts ($)	Downtime ($)	No. of Units	Parts ($)	Downtime ($)	No. of Units	Units	Parts	Downtime
02	68 000	269 000	275	63 000	317 000	159	36.6	48.3	54.0
03	144 000	172 000	437	233 000	379 000	308	41.3	61.8	68.8
04	180 000	111 000	482	198 000	133 000	246	33.8	52.4	54.5
05	109 000	217 000	487	114 000	214 000	199	29.0	51.1	49.7
07	125 000	90 000	456	153 000	178 000	247	35.1	55.0	66.4
08	109 000	164 000	454	160 000	227 000	229	33.5	59.5	58.1
58	77 000	49 000	324	111 000	66 000	190	37.0	59.0	57.4
61	115 000	107 000	406	220 000	174 000	288	41.5	65.7	61.9
62	144 000	251 000	395	210 000	444 000	248	38.6	59.3	63.9
41	75 000	120 000	313	68 000	144 000	146	31.8	47.6	54.6
Total	1 146 000	1 550 000	4029	1 530 000	2 276 000	2260	35.9	57.2	59.5
Department total	1 243 000	1 653 000	4409	1 568 000	2 335 000	2364	34.9	55.8	58.6

received but should be performed when repair limits are exceeded. Currently, the large backlog of uneconomical equipment prevents successful application of the procedure.

The procedure for physical acquisition and disposal represents one aspect of the replacement dilemma. The time interval between selection of the type of equipment to be ordered for replacement and the physical disposal of a unit is approximately one year. This means that prediction of the future is necessary in order to identify equipment to be ordered. Although the equipment management system has proved effective for this purpose, it is difficult for field personnel to ignore the current condition of equipment and make this projection based on statistics. Poor current condition usually causes managers to order a replacement unit. During the delivery period, extensive repairs may be needed due to the pressure of operational commitments. When the replacement unit is received, another unit in poor current condition is selected for retirement. This is not necessarily an economic decision and means that replacement planning and execution are based on current condition rather than on economics. Although the long-range economic factors more accurately predict total downtime and interruption to operations, this is not immediately visible unless one believes in the effectiveness of statistical analysis and prediction. Most field personnel are not trained in these sciences and are reluctant to believe these predictions on faith alone.

Consider the data on dump truck 140-818 given in Table 6. As one can see, the accumulated unit cost of this unit started out high and continued to decrease until a minimum point was reached, at which time the influence of repairs and downtime caused the accumulated cost curve to increase. The repair limit was exceeded in FY 1978, and the unit was placed on the disposal run and given a priority of 1397 of 2692 units. The following year, another repair required the expenditure of $746 for parts and moved the unit up to priority 1118 of 2681 units. The next year, a repair parts expenditure of

$4329 was required, and the unit leaped to priority 372 of 3250 units. If this dump truck could have been replaced at the time optimum replacement was identified, more than $5000 in parts cost alone could have been saved. Short-sighted analysis of current condition by field personnel is responsible for many similar cases.

Although some types of equipment tend to occupy high priorities on the disposal listing, each unit is analyzed based on its performance history. For example, mowing machines tend to have high priority levels while passenger vehicles tend to have low priority levels. This is because mowers usually have higher operating costs, higher downtime costs, and lower capital costs than automobiles. The priority analysis provides an objective method of ranking replacement need. This presents another dilemma.

Field personnel have been conditioned over the years to replace equipment groups each year. One year mowing machines are selected, the next year dump trucks, and so on. Evaluation of the facts indicates that this is a fallacious procedure. Mowing machines do not all fail in one year and dump trucks in another year. Grouping replacement in this manner builds in problems for the future. The field manager must learn to believe in the effectiveness of statistical analysis rather than in past procedure.

There are other problem areas that are related to the equipment shop. The "sunk cost syndrome" causes shop personnel to attempt to retain equipment well beyond its economic life because of previous repairs. There is a tendency to try to recover the cost of the last repair. When costs begin to compound, this thinking results in sending good money after bad, as Table 6 indicates. In order to effectively manage second-line equipment, pools must be established that require management effort for control. This adds management difficulty at the field level. It is much easier to distribute all equipment to the first-level supervisor and not worry about equipment pools and the scheduling problems associated with them.

Many equipment users suffer from an "in-case" disease. This is the desire to retain equipment in case it is ever needed. Since the fleet, unlike personnel, does not naturally decrease in size if no action is taken, machines will remain in the field and deteriorate. Finally, there is a natural tendency for equipment users to want to replace units that are awaiting repair without regard for the economics of this decision. The increased downtime that results produces greater user delays and higher costs than would be experienced if the economic model were used. These problems must be resolved by support from top management and training of field personnel.

Table 4. Evaluation of current condition: both challenging and defending units on disposal list.

Item	Defending Unit[a]	Challenging Unit[b] Before Failure	Challenging Unit[b] After Failure
Repair estimate ($)	0	0	7 859
Priority	1.1	0.90	2.57
Rank	261	364	50A
Age (years)	10	6	6
Retention cost ($)	11 520	9 322	15 581
Total use (h)	12 013	4 610	5 378
Total cost ($)	17 431	18 963	26 822
Replacement cost ($)	11 950	11 950	11 950

[a]1971 International 1600 dump truck 140-512.
[b]1976 International 1600 dump truck 140-908.

Table 5. Evaluation of current condition: defending unit on disposal list.

Item	Defending Unit[a]	Challenging Unit[b] Before Failure	Challenging Unit[b] After Failure
Repair limit ($)	0	465	465
Repair estimate ($)	0	0	1195
Priority	0.10	NA	0.11
Rank	2578	NA	2435A
Age (years)	10	10	10
Retention cost ($)	875	NA	1045
Total use (miles)	53 282	76 909	84 600
Total cost ($)	6 227	6 043	7 238
Replacement cost ($)	11 700	11 700	11 700

[a]1972 Dodge D200 0.75-ton pickup 132-418.
[b]1971 Dodge D200 0.75-ton pickup 132-364.

FUTURE PLANS

Department management is currently supporting the concepts advocated during development of the equipment management system. There are plans to meet with district administrators and conduct training sessions by using data available at the computer terminals and case-by-case analysis in an attempt to convince field managers of the effectiveness of the system.

The equipment that will be retained in FY 1982, in order to replace equipment that was lower on the priority list, has been identified. The districts have submitted plans for reducing the cost of this equipment. It is hoped that next year the predictions made by field personnel concerning these specific equipment units can be compared with the predictions made by the management system to help convince those in doubt that the accumulated cost economic model is a reliable prediction tool.

The expenditure of $250 000 to develop an equipment management system allowed the Department to present the alternatives given in Table 7 to the 1979 session of the Louisiana Legislature. The active fleet consisted of approximately 7400 numbered equipment units with the exception of marine units, aircraft, and units not suited to quantitative analysis. The equipment management system revealed that 2500 units, one-third of the fleet, with a current replacement cost of more than $36

Table 6. Cost history of a dump truck.

Year	Parts Cost ($)	Depreciation ($)	Downtime Cost ($)	Use (h)	Accumulated Unit Cost ($)	Repair Limit ($)	Priority (no. of units)
1975	135	1918	NA	713	2.88	5328	-
1976	244	320	NA	1310	1.29	3712	-
1977	1083	266	NA	1258	1.21	1411	-
1978	1758	266	485	1075	1.48	1186	1397 of 2692
1979	746	266	1304	1201	1.58		1118 of 2681
1980	4329	213	1933	603	2.48		372 of 3250

Note: 1975 International 1600 dump truck 140-818 (initial cost = $5328).

Table 7. Predicted effect of funding alternatives.

Fiscal Year	No. of Units	Replacement Expenditures ($)	Operating Cost ($)	Replacement and Operating Cost ($)	Accumulated Total Cost ($)
Alternative 1: Five-Year Projections Assuming Funds at Present Levels					
1977/78	7441[a]	4 591 789[a]	13 466 682[a]	18 058 471[a]	
1978/79	7213[a]	4 958 497[a]	15 615 874[a]	20 574 371[a]	
1979/80	7213	4 855 358[a]	18 100 000	22 900 000	
1980/81	7213	5 500 000	21 000 000	26 500 000	26 500 000
1981/82	7213	6 050 000	24 350 000	30 400 000	56 900 000
1982/83	7213	6 660 000	28 250 000	34 910 000	91 810 000
1983/84	7213	7 320 000	32 770 000	40 090 000	131 900 000
1984/85	7213	8 050 000	38 010 000	46 060 000	177 960 000
Alternative 2: Five-Year Projections Assuming Funds at Requested Levels					
1977/78	7441[a]	4 591 789[a]	13 466 682[a]	18 058 471[a]	
1978/79	7213[a]	4 958 497[a]	15 615 874[a]	20 574 371[a]	
1979/80	7213	4 855 358[a]	18 100 000	22 960 000	
1980/81	7213	13 200 000	19 140 000	32 340 000	32 340 000
1981/82	6500	14 520 000	21 100 000	35 620 000	67 960 000
1982/83	6500	6 660 000	21 640 000	28 300 000	96 260 000
1983/84	6500	7 320 000	25 100 000	32 420 000	123 680 000
1984/85	6500	8 050 000	29 120 000	37 170 000	165 850 000

Note: Replacement expenditures after FY 1981/82 adjusted for increase from current level at 10 percent rate.
[a]Actual.

Table 8. Capital funding plan: six-year projections assuming funds at requested levels.

Fiscal Year	Category[a]	No. of Units[b]	Replacement Expenditures[c] ($)	Operating Cost ($)	Replacement and Operating Cost ($)	Accumulated Total Cost ($)
1978	Actual	7441	4 591 789	13 466 682	18 058 471	
1979	Actual	7213	4 958 497	15 615 874	20 574 371	
1980	Predicted	7213	4 855 358	18 100 000	22 900 000	
	Actual	7248	4 040 431	19 807 445	23 850 000	
1981	Predicted	7213	10 048 483	22 980 000	33 030 000	33 030 000
	Actual	7268	9 940 304	23 664 586	33 604 890	33 604 890
1982	Predicted	6850	11 053 000	25 730 000	36 780 000	69 810 000
	Actual					
1983	Predicted	6500	12 159 000	28 820 000	43 290 000	113 100 000
	Actual					
1984	Predicted	6500	7 320 000	31 130 000	38 450 000	151 550 000
	Actual					
1985	Predicted	6500	8 050 000	33 620 000	41 670 000	193 220 000
	Actual					
1986	Predicted	6500	8 860 000	39 000 000	47 860 000	241 080 000
	Actual					

[a]"Predicted" as of October 10, 1980, when fleet upgrading changed from a two-year to a three-year program.
[b]Includes active equipment only and excludes attachments such as dump bodies.
[c]Replacement expenditures after FY 1982/83 adjusted 10 percent/year for inflation over expected FY 1979/80 level of $5 million.

million, had exceeded economic service life. Units that should have been replaced were not replaced at the optimum time because of a lack of capital outlay funds and the absence of an accurate method for economic analysis of replacement needs. Correction of the existing replacement backlog required a coordinated approach to (a) increase capital expenditure for two years to upgrade the fleet and clean up the backlog and (b) remove from the fleet all equipment with such a low rate of use that retention was not justified. The capital acquisition part of the plan would require $13.2 million annually for two years (adjusted for inflation). After the second year, acquisition costs were expected to drop to current levels. The combined repair shop and operating cost savings, including the initial higher acquisition cost, would result in net savings over a four-year period. If replacement of equipment were continued on an optimum cycle, savings would continue to accrue. These savings were estimated at approximately $6 million/year once the backlog of high-cost equipment was eliminated.

Although the capital outlay request was subsequently rejected because funds were lacking, the procedure was accepted as a step toward better government and more effective use of available equipment funds through better decisionmaking. The legislative dilemma has been to provide the "seed money" to cause savings to be realized. Initial investment in capital outlay for equipment to produce savings in later years represents a classic legislative problem. Better equipment management may produce lower cost, but it is not as readily visible to the voting public as are other competing capital outlay projects. The three-year term required to yield savings represents another problem for legislators, who may fail to return to bask in the success of this endeavor in the third year.

In FY 1981, the capital funding plan was modified by the Legislature to accomplish replacement over a three-year period instead of a two-year period (see Table 8). The first year of the plan was funded; this increased capital outlay funds by $5 million over the previous year. During the 1981 session, the second year of the plan was also funded. Funding of the remaining year will await evaluation of progress during the first two years of the program.

In spite of the many problems facing equipment managers, there is reason for optimism in Louisiana. The internal problem may be solved if the legislative problem can be overcome. The legislative problem appears to have been resolved by effectively communicating the benefits of sound equipment management to key decisionmakers. Resource management concepts have come to Louisiana with the objective of redesigning accounting and data processing systems so that users' needs for fast, reliable information can be addressed. A maintenance simulation model is being used to provide equipment managers at all levels with a means of evaluating equipment capacity and numbers with greater understanding and appreciation for the problems of operating personnel. Finally, inventory management with attendant equipment parts management potential is on the horizon and may be implemented as soon as the resource management effort is completed.

The Department believes that the issues have been faced squarely and an environment for improving equipment management has been developed. Support systems have been planned and programmed to provide the field manager with objective data on which to base fundamental equipment decisions. Flexibility has been built into the design to enable rapid response to improve concepts. The entire system has been tested and will work. It still remains to be seen whether field managers can actually produce the anticipated savings and effectively realize the potential created by this effort.

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Abridgment

Maintenance Managers Versus Equipment Managers: Their Adversary Relationship

MARTIN C. RISSEL

There is a natural adverse relationship between the highway maintenance hierarchy and the equipment procurement and maintenance hierarchy within the same highway agency as a result of the difference in their primary functions. Modern highway maintenance techniques require the use of substantial varieties and amounts of equipment. Due to declining availability of funds, maintenance managers are becoming increasingly cost conscious and more aware of all expenses contributing to total cost. Tighter control over activities has resulted in a decline in the per-unit use of equipment, and the income or transfer of funds to equipment sections has not kept up with depreciation. Slower replacement of older equipment has caused an increase in downtime due to equipment malfunction. As efforts are made to increase funding for equipment sections, maintenance managers perceive that they are receiving less service for more money. At the operational level, equipment operators believe that equipment downtime is caused by poor equipment selection and repair, and mechanics believe it is caused by operator carelessness and abuse. Recognition of the adversary relationship and its causes can result in increased efforts to design and implement effective equipment management systems that are responsive to change and track all equipment costs and use in a timely manner. In addition, the training programs used to introduce changes or make additions to equipment management systems can be far more effective if both the potential for resentment and the difference in viewpoints are taken into account.

The adversary relationship that tends to occur at essentially all levels of the highway operations-maintenance and equipment procurement-repair hierarchy is the natural result of the generally erratic evolutionary growth of most state highway agencies. When highway commissions or departments were first formed in the early 1900s, the fledgling highway industry was a very labor-intensive one. Federal legislation in 1921 established a federal-aid highway system, but the law also limited the mileage to 7 percent of a state's total public highway mileage. As a result, the various state legislatures assigned responsibility by law for highway construction and, therefore, maintenance in a bewildering array of combinations and permutations. Highway maintenance programs evolved from the abutter working off his taxes to a publicly paid highway patrolman maintaining "his" section of highway using his own equipment and assisted by a helper.

In addition to owner-operated, horse-drawn maintenance equipment and then trucks, $139 million worth of surplus military equipment was provided to states in 1920 as a result of federal legislation to assist them in highway construction and maintenance. As more highways became hard surfaced, the need for specialized equipment arose in the late 1920s and early 1930s with the advent of formal tar or resurfacing crews. Equipment operators working after hours with the assistance of their oilers, which was a usual practice at one time, could no longer supply the necessary upkeep and maintenance for this equipment, and so full-time mechanics became necessary. This evolutionary process produced a great array of management approaches by highway departments, but by the early 1950s most states had fairly well-established formal management relationships between highway equipment and highway maintenance organizations. During this same period, individual patrolmen were being assigned to patrol crews under the direction of a foreman, and private trucks were being replaced in increasing numbers by state trucks. Equipment operators were becoming less responsible for the care and upkeep of their equipment and more dependent on formal equipment management organizations and their mechanics.

In the 1960s, highway maintenance management systems were introduced and, concurrently, equipment maintenance management became more specialized and complex. As a result, highway maintenance managers became increasingly concerned with productivity in terms of ton miles and similar measurements. The equipment managers, on the other hand, tended to concentrate on technical aspects of equipment. At the lower end of the equipment and highway maintenance hierarchies, many equipment operators believe equipment downtime is caused by improper equipment selection and poor maintenance, whereas many other mechanics believe that downtime is caused by operator carelessness and abuse. Most administrators in the highway maintenance field have had all too many opportunities to attempt to resolve personnel difficulties arising from these two points of view.

This controversy has undoubtedly existed since equipment operation and maintenance were first separated, but as long as fleets were expanding and new equipment was frequently purchased it did not have a particularly serious effect on work or employee efficiency. Since the early 1970s, however, when inflation started increasing faster than revenues, competition for the highway dollar has become greater. Equipment costs started increasing faster than the general inflationary trend, replacement programs slowed, and average equipment downtime started to increase. The equipment-using side of agencies became more conscious of unit costs and improving production by using large amounts of equipment but for shorter periods of time. There are equipment costs, however, that occur regardless of use, and hourly rates of use rose rapidly. Fewer dollars, higher charges, and more downtime could only result in worsening relations and increasing turmoil between the highway maintenance personnel and the equipment specialists.

The disagreements that naturally arise between two segments of an organization that have different goals and only one source of insufficient funding cannot be eliminated, but they can be greatly reduced by a logical approach to the problems that create the disparity of opinion. In this case, only a businesslike, precise, well-designed, and responsive equipment management system will suffice. All costs of equipment must be collected without exception; and, based on these costs, rental or use rates that are fully auditable and justifiable to everyone must be established. These rates should be dual in nature, and charges should be made based on daily possession of equipment for fixed costs such as depreciation and insurance. No possession charge should be made for equipment that is inoperable or unavailable for use, and consequential costs should be absorbed by the equipment section. On the other hand, maintenance managers who are working with correctly structured budgets and who are charged realistic rates for possession of equipment will have ample incentive to ensure that they have no more equipment than necessary. The operation portion of the rate must also be precise and accurately reflect true costs. Obviously, collecting and assigning all costs and correctly recording all use require that joint decisions be made by equipment managers and maintenance managers as part of the development of an effective equipment management system. This cooperative effort is a major step in reducing the effect of the adversary relationship of the two sides.

Not only will improved relationships and better efficiency result from a soundly designed equipment management system, but also direct and sizable financial benefits will accrue to the parent organization. As an example, one only needs to compare the fuel cost per hour between the bestand poorest-operated and maintained equipment to realize the possible savings to an agency that employs properly trained drivers operating correctly maintained equipment.

In summary, the common ground between the equipment manager and the maintenance manager is concerted action to hold down equipment costs, but only a correctly constructed and operated use-rental rate system will suffice as a tool. In addition, each manager must be assigned responsibility for work performed by his or her organization and funds budgeted for its performance.

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Development of Parts and Materials Inventory System

DOUG NIELSEN

The Parts and Materials Inventory Subsystem (PMIS), one of four interrelated subsystems in the equipment management system under development by the Arkansas State Highway and Transportation Department (ASHTD), is described. The established user objectives of PMIS are to (a) maintain parts inventory balances, (b) support established fill-rate objectives, (c) set efficient limits on stock levels, (d) control stock replenishment actions, and (e) evaluate inventory management performance. Additional desired features include interdistrict checking to locate a needed item stocked elsewhere in the state and error-free distribution records for accounting. Due to various inadequacies in the existing method of numbering stock, new numbering schemes were devised for all inventory items and stockpile locations. All stock items and locations were then converted to the new numbers. The PMIS design specifies on-line computer terminals in each district stockroom to process normal accounting transactions and meet user needs. Inventory transaction information is input at the district and subjected to detailed editing to ensure data integrity. Balancing and editing routines permit all error correction to be made at the data source. Various stock management reports are provided in on-line and batch modes for district and Central Headquarters. PMIS operations were tested in two ASHTD districts. Prearations are under way for statewide implementation.

In April 1979, the Arkansas State Highway and Transportation Department (ASHTD) entered into a contract with the Federal Highway Administration (FHWA) to test and evaluate an equipment management system (EMS) based on an EMS Manual developed by a consulting firm under another FHWA contract. Since an EMS must be tailored to the particular needs of the user, ASHTD was authorized to make whatever changes in the Manual recommendations it deemed necessary to accomplish this task. The contract term is three years, and FHWA is funding approximately 25 percent of the total cost.

An interdepartmental project team was formed within ASHTD to plan and carry out implementation of the EMS and monitor progress. The team is composed of representatives from the Fiscal Services Division, Computer Services Division, and Equipment and Procurement Division. Advising the project team are personnel from the Maintenance Division, several districts, and the Internal Audit Section.

Several functions must be dealt with in an EMS to achieve desired equipment use. This involves various equipment-related activities, such as acquisition, assignment, daily use, preventive maintenance, repair, and eventual removal from use and disposal. In addition, the consumption of various resources, such as labor, parts, fuel, and outside services, must be considered.

EMS SUBSYSTEMS

To meet the information requirements to manage this multifaceted operation, the ASHTD EMS is composed of four interdependent subsystems. These subsystems are being developed and implemented on a priority basis determined by ASHTD's existing systems and areas of most pressing need. Each of these individual systems is briefly examined below in the chosen order of development.

Parts and Materials Inventory System

The Parts and Materials Inventory System (PMIS) will maintain a file of all equipment parts and other materials stocked throughout ASHTD together with balances on hand at each stocking point. The system will periodically analyze parts use, recommend stock levels and reorder quantities, and produce stock replenishment notifications when stock balances fall below established levels. PMIS will relay parts and materials cost data to two other EMS subsystems: the Equipment Maintenance and Operations Cost System and the Equipment Cost Accounting System.

Equipment Maintenance and Operations Cost System

The Equipment Maintenance and Operations Cost System (EMOCS) will collect all direct equipment ownership (purchase cost, depreciation, etc.), maintenance (labor, parts, etc.), and operations (fuel, oil, etc.) cost data and maintain histories of charges to each unit in the equipment inventory. To permit computation and reporting of per-mile and per-hour costs, the system will also maintain current levels of equipment use.

Data necessary for most of the analytical reports required by equipment managers at all levels will be stored by EMOCS. Cost analyses for equipment replacement decisions, preventive maintenance program evaluation, and repair shop staffing and resource allocation will be generated by this system.

Incorporated into this system will be the primary means for controlling scheduled repair and inspections, nonscheduled maintenance, and repair backlogs. It will record actions taken to expedite parts and repairs for units that have been out of commission for long periods. The system will provide control of equipment downtime and responsibilities related to equipment maintenance.

EMOCS will draw charges for parts issued to equipment from PMIS. In addition, it will collect equipment cost data, such as depreciation, from the Equipment Cost Accounting System and, in turn, will supply data for allocating indirect and overhead costs to the Cost Accounting System.

Equipment Cost Accounting System

The Equipment Cost Accounting System (ECAS) will provide an interface between existing accounting systems and the cost collection and analysis systems developed specifically for equipment management purposes. It will permit the collection of all indirect, overhead, and administrative costs related to equipment ownership, operation, and maintenance and will distribute them to equipment classes for budgeting and cost-reporting purposes.

This system will collect direct costs obtained through EMOCS and data to allocate indirect overhead costs. It will thus provide the means for developing and charging comprehensive equipment rental rates, developing program budgets, and reporting actual cost performance against these budgets. Finally, this system will feed necessary expenditure data to inventory and depreciation accounts.

Equipment Control System

The Equipment Control System (ECS) will maintain a master inventory of all equipment in the complement and provide the means to record changes in the inventory and in equipment assignments. Equipment unit records will include significant descriptive data on equipment units, current assignments and location, and current and recent levels of use. The system will generate reports that show equipment assignments and analyses of equipment use.

Use summaries will be produced to permit the development of rental rate charges. Input from the ASHTD Maintenance Management System will permit maintenance-crew equipment needs to be evaluated and complements to be established. The equipment planning component of the ASHTD Construction Management System will be used to establish Construction Division equipment needs.

Several equipment control procedures already existed in some form within ASHTD operational procedures prior to EMS development. Most of these, however, were not dependent on or coordinated with other equipment programs; they were complete units in themselves. EMS will collect and update these elements and expand into other areas to form one cohesive, interrelated system.

PMIS

For the sake of internal organization and distribution of the workload in the ASHTD Computer Services Division, two project leaders were designated to coordinate the design and programming of various EMS phases: one for PMIS and the other for the remaining three subsystems.

Due to user concern over the inadequacies of the existing inventory system, PMIS was given the highest development priority. The bulk of our development work to date has been on this subsystem, and it is the primary focus of this paper.

The initial task of PMIS development was to get the users of data from the subsystem to list the objectives that they felt PMIS should address. The basic objectives of PMIS were to

1. Maintain parts inventory balances,
2. Support established fill-rate objectives,
3. Set efficient limits on stock levels,
4. Control stock replenishment actions, and
5. Evaluate inventory management performance.

Additional desired features included

1. Interdistrict checking, which provides a method for determining whether any district stocks a part another district needs and whether they actually have any on hand;
2. Capability for establishing and showing reorder points for stock when a minimum level is reached; and
3. Error-free distribution records for accounting.

The capability of interdistrict checking and maintaining stock at an optimum level will reduce repair backlogs and equipment downtime and increase labor productivity and use of shop space. Interdistrict checking and centralized stocking will free the districts from stocking slow-moving, high-cost items. Error-free distribution will improve the integrity of equipment history and, by means of the various equipment management reports, point out problem areas that need attention.

The old automated inventory system was set up 15 years ago for equipment parts. Maintenance materials were maintained on a manual perpetual index-card system. The numbers in the old system were assigned consecutively without attention to grouping of related items. This permitted duplication of numbers. The ASHTD number had no particular significance other than uniform length and format.

One of the requirements of the new inventory system was to devise a new numbering scheme that would accurately identify parts and provide consistency. The numbering scheme chosen consists of eight numerical characters. The first two numbers designate the major group, the second two designate the subgroup, and the last four digits are the sequence number for that item.

The major group identifies the major category of use: e.g., 01--Road Surface Material, 07--Safety and First Aid Supplies. In equipment parts, the major group is a variation of the rental code given to each class of vehicles:

30 Passenger Type and Light Utility Vehicles
41 Crawler Tractors
45 Expendable Supplies (tires, batteries, etc.)

The subgroup further specifies the area of use:

01 Air Induction System
07 Engine
15 Suspension System

For example, disc brake pads for a 1981 Oldsmobile Cutlass are numbered 30180695: The number 30 designates the major group, Passenger Type Vehicles; 18 indicates the subgroup, Wheel and Brake System; and item number 0695 specifies the particular item.

In order to provide a method of isolating various types of stock, a uniform stockpile location numbering scheme was devised. The stockpile location numbers also provide the districts with a means to control stock at the various levels of responsibility. Area foremen are responsible for stock in their counties; the storeroom supervisor is in charge of the parts warehouse, the sign room, and the district yard and can isolate various stock items by the location numbers.

All stock locations throughout each district are identified by a two-digit location number. The following numbers were preassigned for stock maintained at the district headquarters:

01 Parts Storeroom
02 Parts Warehouse
03 Sign Storeroom
04 Salt Storeroom
05 District Storeroom
06-09 Other discretionary stock locations at district headquarters

Sequences of 10 two-digit numbers are assigned to locate stockpiles in each county. The first number in the sequence designates the area headquarters yard in that county. For example, Crittenden County is assigned stockpile location numbers 10-19 in district 1, and 10 designates the Crittenden County area yard. The storeroom supervisor in each district is responsible for keeping up with the stockpile location numbers.

Once all requirements and desired features of PMIS were defined and the item and stockpile location numbering schemes were complete, the team began the process of designing the system of programs necessary to meet user needs. The design specified on-line computer terminals in each of the district stockrooms to provide the system's two primary functions:

1. Processing the normal accounting transactions for issues, receipts, and adjustments while maintaining proper inventory balances and
2. Analyzing parts use and generating stock management information.

As transactions take place, the data are posted on forms that serve as source documents from which the information is keyed into the terminal. The actual keying of the data on the terminal is a new experience for the stockroom personnel. The speed of entry, compared with centralized data entry, has decreased somewhat, but the accuracy of the input data has increased. The timeliness of the data has increased tremendously since the time lost by mailing transactions and corrections has been eliminated.

There are screens for each type of stock transaction: issue, receipt, and direct (outside purchase). For each transaction type, there are separate panels for distribution to tag equipment; county, route, and section; job and federal aid project number; special projects; buildings; rest areas; bridges; resident engineers; and no distribution (used for stock adjustments and nondistributive administrative charges). Each panel has space only for that specific information.

These 19 separate panels were provided so that the data could be entered easily and user exit programs could perform detailed edits on each specific type of distribution. The specialization of these programs ensures data accuracy without a great degree of complexity in the program code.

As the transaction is transmitted, the central computer edits the data for accuracy and returns any errors. Incorrect fields are highlighted, and an error message is shown on the last line of the screen. After each correction, the data are again edited in entirety for errors to prevent any previously correct information from being changed in error. These edits force the user to enter the data as correctly as possible at its source, the district office. Corrections are made by the people who can check the information sources for corrections.

After the district sends a page of data, the page total is entered. The computer will then tally item numbers (called the hash total), quantities, and money for the page. If any of the totals vary, the entire page of data is returned to the district as out of balance. District personnel must then check to see whether all transactions were sent and the correct amounts were entered.

Two media are used to supply information to the various levels of users: on-line and batch. When the amount of data is small and specific and response time is critical, on-line terminal inquiries are used. When details or large volumes of data have to be processed, batch reports are used. As hardware improvements are made and program expertise improves, more applications may be changed from batch to on-line or to a variation of remote job entry.

For the benefit of stock management at the district level, there are screens for description inquiry and detail inquiry. The description inquiry screen displays the item description, specification, manufacturer name and number, old inventory part number, expenditure object, unit of measure, rental code, and cross reference. The detail inquiry screen displays the item description; stockpile number; manufacturer number and name; unit of measure; bin location; on-order quantity, requisition number, and requisition date; last date issued; last date received; requisition number; minimum and maximum stock levels; review point; quantity on hand; unit price; and total dollar value on hand.

Some of the batch reports provided for the districts are as follows:

1. The Consigned Stock List lists all items stocked by each budget in order of stockpile location. Since the area foremen are responsible for the verification of the quantities on hand, a report without quantity and money, with space for these entries, is provided on the last day of each month. The foreman's actual counts are then verified to a run with quantity and money supplied to the districts at the close of the month.
2. The Inventory Listing by Bin Location lists the item number, manufacturer number and name, description, unit of measure, object, bin location, quantity on hand, unit price, and dollars on hand in the bin order in which they are stocked in that particular stockroom. Variations of this program give the district or audit the ability to specify blank quantity and money for auditing, listings for certain aisles or bins for spot verifications, or certain stock locations for checking all stock in that area.
3. There are several microfiche catalogs of the description file: (a) catalog by item number, (b) catalog by manufacturer, (c) catalog by description, and (d) catalog by old ASHTD part number (for conversion only).

Programs for district bookkeeping and fiscal services are as follows:

1. The Inventory Transaction List by Type and Date lists all transactions for each budget by type (receipt, issues, direct) and by date and page.
2. All receipts and directs by requisition number and category are listed in the Inventory Stock Received Journal, which replaces the previous manual posting of this bookkeeping journal.
3. The Inventory Stock Issue Journal carries actions by date for six categories of expense and eliminates the manual posting and tabulations required in the past to prepare this bookkeeping journal.
4. The Out-of-District Equipment Upkeep and Stock Transfers report lists the transaction data for stock charges made to budgets or tag vehicles from other than the originating budget.
5. The Inventory Detail Tab by Budget report lists all stock for each budget and gives a total of both quantity and dollar value on hand.

Programs for procurement and stock-level control are as follows:

1. The Stock Below Minimum report shows all stock items in a district for which the quantity on hand is below their specified minimum.
2. The Stock Above Maximum report shows stock above maximum.
3. The Inventory Stock Activity by Quantity report shows the total quantity used for each item number by district.
4. The Inventory Stock Activity by Dollars report lists the total dollar amount of all issues by item number and district.

There are screens for adding, changing, or deleting parts numbers, descriptions, manufacturer names and numbers, or unit of measure. All of these functions are performed by one individual, the inventory coordinator, located at the Central Headquarters.

As development of the EMS progresses and after a reasonable transaction history file is built, parts use will be used to provide guidelines for establishing fill rates, limits on stock levels, and replenishment activities.

Once PMIS development was complete, it was decided to test the system in a pilot district. Restricting operation of the new system to a small representative group would allow the project team to fine tune the system and more easily address any problems that arose. Actual user feedback could then be incorporated. All operational problems could be resolved before statewide implementation. District 6 at Little Rock was chosen for the initial pilot test because of its proximity to the Central Headquarters. District 7 at Hope was later added as an extension of the pilot testing.

The conversion to the new PMIS was divided into two segments: maintenance stock and equipment repair parts. The old maintenance stock system consisted of a manual index-card file that had the unnumbered items in alphabetic description order. There was lack of uniformity in the actual descriptions and in the semantics used for the same items. However, the card system did provide the capability to verify quantities on hand, unit prices, last issue, last receipt, or last several transactions, since the retrieval of one stock card put all this information in the hands of the stockroom personnel.

Due to this lack of uniformity, the manual task of numbering maintenance stock was very tedious and time consuming: It took about 16 h to number a district's 1500 maintenance items. There was some skepticism among the users about the currentness of data. The old automated Parts Inventory System was a batch system and, due to the time delays in mailing, manual coding, and verification, the actual inventory balances were not reported until 15-20 days after the end of a month. To verify balances on hand, the districts had to reconcile the latest inventory run and the in-transit transactions. In these respects, the maintenance index-card system outperformed the old automated system. Skepticism concerning data accuracy and apprehension as to how central office management might control a district's stock were two of the greatest obstacles the design team had to combat in persuading the users to accept PMIS.

The conversion of the old automated equipment parts system to PMIS was an easier task. Although considerable effort had been expended to eliminate duplicates in the old system prior to conversion, additional duplicates were discovered at conversion. Still, cross-matching was fast and uniform since a number did exist.

The cleaning, purging, and identification of duplicates in the old system took several employee hours. Then the identification of the group and subgroup for each old number became a time-consuming task for several specialized employees using various reference manuals before some parts could be specifically identified. Once a new number had been assigned to all items, catalogs by manufacturer number and description were checked for duplication.

The actual match of a district's stock was merely a sequential match of the old inventory to the new inventory file. Once a match was found, the new item number was issued with the quantity on hand and inventory dollars to create the new inventory file. The user only supplied the bin number by old part number.

After the district's file had been converted, runs were prepared in new number order, old number order, bin order, and manufacturer number order, and all new PMIS catalogs were supplied.

Since the old system was not up to date with the inventory balances, 100 percent audits were made of the quantities on hand. The new system supplies the report used for auditing in bin number order. This report actually reduces the physical count time from about 7 h with the old procedures to 3 h with the new.

The ASHTD Internal Audit Section completed a review of PMIS design documentation and operational procedures. The final report indicated that auditability and control are adequate.

The two pilot districts have conducted periodic inventories of a percentage of their stock as prescribed by ASHTD policy. These partial inventories yielded the least variance ever achieved between actual and book figures in those districts. The pilot districts balanced their year-end inventory within a day of the end of the fiscal year whereas all other districts required about four weeks.

Authorization to proceed with statewide implementation of PMIS has been requested. That decision is being delayed pending legislative action on additional highway funding.

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Abridgment

Routine Maintenance of Highways in Member Countries of PIARC

HENRY DeLANNOY, ALAIN LABEAU, JEAN REICHERT, AND CLAUDE FRÉDÉRIC

The techniques currently used for routine road maintenance are described on the basis of data from the member countries of the Permanent International Association of Road Congresses (PIARC). The planning and control of these works are examined. Details are given regarding the established administrative structure (maintenance districts and maintenance centers) and personnel training. Finally, the financial management of road maintenance is dealt with from the point of view of maintenance costs and analytic accounting. The following areas of needed improvement are noted: greater cost-effectiveness of specific maintenance techniques, the development of more durable materials, the necessity of an overall maintenance strategy, and the continued improvement of analytic accounting.

In member countries of the Permanent International Association of Road Congresses (PIARC), as a result of advances in vehicle ownership and the development of road network equipment, the problems presented by road maintenance have required a total reorganization of the methods used. In Great Britain, the Marshall committee, taking this reorganization as a basis, studied organization and maintenance standards. In France, efforts were for a long time aimed at strengthening strategies for the national road network, while at the same time the Federal Republic of Germany achieved the highly mechanized organization of its motorway maintenance centers.

Nevertheless, it has been felt necessary to adopt a systematic and rational approach to the formulation of overall maintenance strategies. Although maintenance budgets have traditionally been drawn up on the basis of the budget for preceding years, it has now been confirmed that the establishment of these budgets with respect to levels to be achieved is desirable. Currently, the procedure used in most countries combines both approaches.

TECHNIQUES

As a result of the increase in traffic and the degree to which roads are equipped, it has proved to be necessary to work out maintenance techniques that are both more suitable and more economical. The improvements made in these techniques have to do chiefly with the increasing mechanization of works, which in turn is the result of more efficient plant better adapted to maintenance tasks and the use of improved materials.

Patching is in most countries the largest item in day-to-day pavement maintenance. Patching may be used to remedy local deficiencies of a pavement in good condition and also to maintain minimum service levels over a short period on a damaged pavement for which major repairs have been scheduled. Ways of mechanizing the process to the greatest extent possible are currently being studied.

The patching of flexible pavements consists of making emergency repairs of defects such as potholes, local depressions and cracks, or incipient peeling, by the following methods:

1. The means involved in temporary patching are very limited: cleaning with a brush, spreading with a shovel, and tamping with a rammer.
2. Permanent patching consists of removing the unstable material by cutting with a saw, filling the cut with a bituminous material, and completing the operation by laying a bituminous surfacing mix. Special bituminous mixes are being tested in the Federal Republic of Germany and in Finland.
3. The sealing of surface cracks is done with a coat or with a thin layer of hot-laid sheet asphalt.

As for the patching of rigid pavements, a current practice in a number of countries is the use of thin concrete layers for the repair of scaled and peeled surfaces.

The purpose of sealing the joints in cement concrete pavements is to prevent the infiltration of water into subjacent layers and to prevent aggregate from entering the joint. A distinction is made between (a) local repair, which is often carried out by government agencies and consists in cleaning the joint and applying a warm sealant, and (b) general repair, which is often executed by a specialized firm and consists of stripping the sealant out of the groove, cleaning the groove, and applying new sealant.

For sealing, three main types of materials are used: (a) hot-injected sealing compounds (most commonly used), (b) cold-injected mastics (used only for local maintenance), and (c) rubber (neoprene) compressible strips (used in new construction).

Pavements with base courses that have been treated with hydraulic or pozzolanic binders, paved with a thin or average layer of bituminous material, will after a period of time show reflection cracks. Routine maintenance calls for the sealing of these cracks with fluidified, possibly modified, bitumen. The most striking positive aspects of crack sealing are an improvement of imperviousness and, consequently, an improvement in the bearing capacity of the wearing course and in its resistance to freeze-thaw cycles and to deterioration as well as the relatively low cost of the repair. Drawbacks worth noting are an appearance and evenness that often leave much to be desired, a relatively short life-span (generally less than a year), and the low productivity entailed in the sealing process.

A major effort has been made in the past few years to achieve a greater uniformity of horizontal markings on national road networks. Various countries have thus been induced to introduce a preliminary approval procedure for marking products. As a result, the quality of horizontal road markings has significantly improved.

Road marking is most often done with road paints and hot coatings; cold coatings and glued strips are also used but less frequently.

Painted markings usually have to be restored every one or two years depending on the intensity of the traffic. The restoration of markings made with hot coatings usually becomes necessary two to six years after their application. In countries where studded tires are widely used, hot coatings usually last three to four times longer than paints. The use of cold coatings and glued strips is restricted to urban areas.

Illuminated road-sign equipment is maintained by the awarding authorities, and the works are carried out by subcontracting firms (who are often the constructors themselves) or, in some large towns, by the municipal engineering services. Maintenance work for nonilluminated signs consists of the cleaning, repair, and replacement of signals as well as cutting back vegetation in order to improve visibility.

The maintenance of green areas is closely related to local relief, climate, the density of traffic on the road, and the status of the road. Because of this diversity, there are no exact standards for the various types of maintenance required, except in some countries where the frequency of maintenance is stipulated. The mowing of embankments at least once a year is more or less systematic except on certain extremely secondary roads. In France, it is thought that grass should not exceed 20-40 cm in height, which means that mowing is required two or three times a year. The use of growth inhibitors in spring has generally been held up by ecological considerations, except in a few countries. Mowing is most often mechanized; the traction units used may be either agricultural tractors or, less frequently, cross-country vehicles.

Cutting tools are also often of the agricultural type (cutting bars with blades, circular cutters, or disks), the productivity of which is well known. Drums with mobile arms and cylindrical rotors onto which knives are fitted are increasingly used. These machines are known as brush clearers.

Road-cleaning operations cover the trafficked areas and the gutters as well as the edges of the road and rest areas. The equipment used usually consists of sweepers and gully emptiers.

WORK PLANNING AND CONTROL

For the work organization, the choice of the type of operation, as well as the required plant, is settled in different ways from one country to another. Urgent maintenance operations are usually carried out by bodies controlled by the road authorities, whereas many other activities that are not so urgent and that require the use of construction plant are more often entrusted to private firms.

The system of individual maintenance was progressively replaced by a team system equipped with suitable vehicles and plant. Since then the team system has been modified so that each task is performed by increasingly flexible groups, consisting of one to four men and equipped with the vehicles and equipment required.

Work is usually planned on the basis of an analysis of pavement condition. This is carried out--at least for the national road network--by means of systematic visual inspection as well as by high-yield measuring equipment.

The parameters measured are skid resistance, bearing capacity, rutting, and evenness. The measurements are then correlated to surface defects determined either by photographic inspection or by systematic visual inspection, which remains the most common basic element in the determination of maintenance requirements. Apart from the visually determined data, these data are increasingly entered into road data banks and used for planning maintenance.

In all PIARC member countries, the road network to be maintained is divided into districts. The size of these districts varies considerably according to the structure of the network of which the road is a part, its topography, and the density of the traffic. The maintenance of motorways is not separated from the maintenance of other roads except in countries that have large motorway networks. For motorways, a district usually covers 50-60 km, though where networks are extremely dense a district may comprise as much as 120 km. For other roads, the size of the district varies enormously, from less than 100 km to more than 400 km. This depends on the structure of the network--more precisely, on the time required to reach all points on the network, the optimum being between 1 and 1.5 h.

Maintenance centers managed by the road authorities are generally entrusted with the following tasks: the supervision of the condition of the road and its ancillary equipment, work preparation, emergency services, certain specific tasks (such as maintenance of appurtenances), acting as principal contractor for work performed by private enterprise, and often patching and winter maintenance.

Radio communications are increasingly used. In theory, a base radio station is found in each maintenance center. This means of communication is very useful, allowing all maintenance vehicles to be in constant contact with the road maintenance center.

The number of personnel employed permanently on road maintenance depends on local conditions. In most countries, one man for each 6-7 km of maintained road is employed, not including administrative and management staff. These figures may vary considerably, however, and in some cases ratios may be as low as one workman per 25 km. On the other hand, 25 men may be required for the maintenance of 50 km of motorway because operating requirements are far stricter.

FINANCIAL MANAGEMENT

One of the critical elements in maintenance management lies in the financial control and analysis of expenditure, which should make it possible to determine the order of priority of the maintenance budget. Nevertheless, despite the fact that this expenditure represents a considerable portion of national spending, people are generally very badly informed on maintenance costs.

Any comparison of maintenance costs at an international level appears to be impossible. This is because of the diversity of administrative structures, the differences in the significance of budget items, and the variety in the applied standards and budget controls.

The application of an analytic accounting system, more or less at maintenance-center level, seems to be spreading. This is necessary if all expenses are to be related to each type of road involved and to each type of task. In Switzerland, the Federal Road Service has developed an analytic accounting system for motorway maintenance centers. Operating expenses are accounted for by type of task and by section of motorway. The processing of data on small office computers allows a thorough analysis of operating results.

CONCLUSIONS

1. This paper has noted the progressive introduction of specialized low-cost maintenance techniques, which are the result of productive equipment more suited to maintenance tasks, and the introduction of materials with improved properties. However, an effort must still be made to improve the cost-effectiveness of certain techniques such as the patching of flexible pavements and of cement concrete. More durable materials for patching flexible pavements, for repairing cracked semirigid pavements, and for sealing joints in cement concrete pavements are currently being studied.

2. The use of rational methods for formulating an overall maintenance strategy based on target levels is increasing, and the scanning of national road networks is becoming more widespread. However, problems regarding the analysis and interpretation of visual and photographic inspections remain to be solved. Various countries use the data stored in a data bank for planning maintenance, sometimes in conjunction with the data contained in a technical guide to maintenance.

3. In the majority of countries, maintenance centers have been set up that are run by the road authorities and are entrusted with the task of carrying out road maintenance operations at regular intervals. Major improvements have been made in their operation, largely as a result of the installation of radio communications.

4. One of the critical elements in maintenance management is the analysis of expenditure, but to date people are still very badly informed about maintenance costs. However, the continuing introduction of analytic accounting systems should provide greater insight into maintenance expenditures.

5. Advances in road maintenance must be assimilated and actually applied by the personnel involved. A major effort is under way to introduce local staff to new techniques and to train new personnel.

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