An Evaluation of Flagging Techniques and Devices on Two-Lane Highway Construction Zones

WA-RD 160.1

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June 1988

Washington State Department of Transportation
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in cooperation with the
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ERRATA

"An Evaluation of Flagging Techniques and Devices on Two-Lane Highway Construction Zones", WA-RD 160.1 Final Report, June 16, 1988.

The following paragraph replaces the first full paragraph on page eight of this report:

According to the MUTCD, the following methods of signaling with sign paddle (primary signaling device) should be used:

1. To STOP Traffic. The flagger shall face traffic and extend the STOP 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.

2. When it is Safe for Traffic to Proceed. The flagger shall face traffic with the SLOW sign paddle held in a stationary position with the arm extended horizontally away from the body. The flagger motions traffic ahead with the free hand.

3. When it is Desired to Alert or Slow Traffic. The flagger shall face traffic with the SLOW sign paddle held in a stationary position with the arm extended horizontally away from the body.

AN EVALUATION OF FLAGGING TECHNIQUES AND DEVICES ON TWO-LANE HIGHWAY CONSTRUCTION ZONES

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16. ABSTRACT

Various methods of controlling traffic through construction zones are examined. The accident statistics concerning construction flagging are summarized, indicating the need for improvements in construction flagging techniques. A research methodology is presented for implementing and evaluating several flagging techniques.

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CHAPTER 1
INTRODUCTION

In recent times, as vehicle traffic has increased, the challenge to improve safety conditions at highway work zones has magnified. With the increasing emphasis on highway reconstruction and less emphasis on new construction, safe traffic control through these projects has taken on new importance.

For years, flaggers have successfully controlled traffic during lane closures on two-way, two-lane highways. However, an increase in work zone accidents involving construction workers has become a source of major concern for state transportation departments nationwide. On Washington state highways, the total number of yearly work zone accidents has increased from 455 in 1980 to 1279 in 1985. Table 1.1 shows the current trend in work zone accidents.

Flaggers are provided at highway work sites "to stop traffic intermittently as necessitated by work progress or to maintain continuous traffic past a work site at reduced speeds to help protect the work crew" (2). More specifically, flaggers are used to perform the following duties (3):

1. to control alternating, one-way traffic through one-lane work zones on two-lane, two-way highways,
2. to stop traffic intermittently at a work zone to allow vehicles to enter or exit the roadway,
3. to improve driver awareness of warning signs,
4. to give the motorists special instructions for driving through the work area, and
5. to improve driver compliance with posted speed limits through the work zone.

The aim of this study is to develop a procedure for studying the relative effectiveness of traffic control devices that could be used in lieu of procedures recommended by the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) (2).

One original purpose of this study was to conduct field evaluations of three flagging techniques (MUTCD flagging, traffic signals and stop signs) at identical two-lane, two-way highway construction sites. However, this plan was abandoned because of difficulties encountered in soliciting projects on which to conduct the tests. As a result, the scope of the research was changed to provide a prototype data collection endeavor that could be used to define a demonstration project in the future.

In addition, this study involved a state-of-the-art review of literature on work-zone flagging, a review of flagger accidents, survey of flaggers and an analysis of the limited data collected.

TABLE 1.1
WORK ZONE ACCIDENTS ON
WASHINGTON STATE HIGHWAYS, 1980 - 1986*

YEAR	FATAL	INJURY	PROPERTY DAMAGE	TOTAL
1980	9	181	264	455
1981	4	202	285	487
1982	1	285	424	709
1983	7	336	464	807
1984	9	369	516	894
1985	8	533	738	1,279
1986	4	483	768	1,255

*Available accident data were obtained from the Headquarters Construction Office of Washington State Department of Transportation.

CHAPTER 2
REVIEW OF PREVIOUS WORK

P.G. Michalopoulous, G. VanWormer, H. Preston, and R. Plum (4) studied traffic control alternatives for one-lane bridges using field data and simulated data. Specifically, they field tested fixed-time traffic signal controls and stop sign controls that alternated traffic on one-lane bridges during construction. Their results indicated that the stop sign control resulted in a higher violation rate but a smaller average queue size and a lower average delay than the traffic signal control.

C.M. Abrams and J.J. Wang (5) studied procedures for planning and scheduling work zone traffic control. They identified evaluation measures for comparing alternative methods of traffic control, as well as techniques for quantifying these measures, listed below as follows:

- accidents,
- vehicle delay,
    - delays due to distance or speed changes
    - delay due to temporary stoppage
- vehicle stops,
- fuel consumption,
- traffic control costs, and
- air pollution.

In their study, R.S. Hostetter, K.W. Crowley, G.W. Dauber, L.E. Pollack, and S. Levine (6) analyzed the kinds of information that drivers need to travel through highway work zones safely and efficiently and how this information can best be conveyed to the driver. The following classes of information needed by motorists were identified:

- general construction approach warnings,
- feature warnings (identify the type of work zone to be encountered, e.g. lane closure),
- maneuver warnings (identify what the driver must do to negotiate features that demand lane changes, turns, or stops),
- feature locations (identify the beginning of the feature),

- prohibitory/restrictive warnings (identify downstream restrictions,)
- speed advisories, and
- route guidance.

During the course of their study, R.S. Hostetter, et al., reviewed 250 work zones of various types and identified the following categories of information problems:

- misleading information,
- improper or non-standard information (message, positioning, condition, use, color),
- non-specific information, and
- contradictory information.

S.H. Richards and C.L. Dudek (6) evaluated traffic control plans at reconstruction sites. Among other things, the authors considered the role of flaggers in freeway work zones. They identified the following traffic control functions that can be performed by flaggers in the freeway work zone:

- control traffic at frontage road intersections and along detour routes,
- close entrance and exit ramps,
- direct traffic through complicated work zones onto shoulders or at ramps within the work zone,
- prevent illegal freeway access,
- alert traffic to special signing (and enhance motorist response to the signing), and
- control speed.

The report identified ramps, frontage roads, detours and route intersections as the best areas for utilizing flaggers. It further concluded that flaggers should be used on the main freeway lanes only in special situations (e.g., for speed control).

D.S. Gendell (Director, Office of Highway Operations, FHWA) in a speech on work zone traffic control, February 1985, reported on a nationwide review of traffic safety through construction and maintenance work zones undertaken by the Federal Highway Administration. The use of improper flagging techniques is a problem that the review identified. D.S. Gendell reported that "in a limited number of locations, it was observed that flagger dress, position, alertness, equipment, and signaling were deficient. This generally indicates a lack of training of flaggers or not enough emphasis on inspection of flaggers, or both. In some cases, flaggers were used where traffic control devices could have sufficed."

S.H. Richards, R.C. Wunderlich, C.L. Dudek, and R.Q. Brackett (8) stated that one advantage of using flaggers in highway work zones is the ease of implementing and the ease of removing flaggers. The disadvantages of flagger usage stated in their report are as follows:

- fatigue and boredom may necessitate frequent relief,
- labor is costly for lengthy applications,
- their effectiveness may decrease with continuous use,
- drivers may have a problem seeing flaggers at night, and
- flagger safety considerations may preclude the use of flaggers at some work zones.

G.L. Ullman, S.Z. Levine, and S.C. Levine (3) compared two traffic control alternatives (fixed-time, portable traffic signal and flagger) for alternating one-way traffic through one-lane work sections on two-lane, two-way highways at three sites, for one hour at each location. They identified the following safety problems during the flagging operations:

- inadequate sight distance to flagger and work zone,
- improper advance or supplemental signing,
- improper flagging communication, and
- improper flagging positions.

These studies suggest that the most promising areas of research on the subject is one involving the field testing of supplemental or alternative traffic control methods in highway construction work zones.

G.L. Ullman, et al., concluded that the use of portable traffic signals could result in substantial savings in flagger labor costs, and that the use of portable traffic signals resulted in minimal increases in motorist delay costs and increases in violation rates.

CHAPTER 3
REVIEW OF EXISTING METHODS FOR CONTROLLING ONE-LANE WORK ZONE TRAFFIC

The search of the relevant literature revealed that there are basically four methods for regulating traffic through a two-way, two-lane highway construction work zone when one lane is closed (2,3,4,5,6,7,8). These traffic control methods involve the use of the following:

- flaggers,
- traffic signals,
- stop signs, and
- yield signs.

FLAGGERS

Flaggers are used extensively nationwide on two-way, two-lane highway work zones where one of the lanes is closed to traffic. The recommended techniques and procedures for flagging practice covered in the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) has been adopted by the state of Washington. The big advantage of using flaggers over the other devices is that they are more flexible, thereby capable of reacting fast to changing conditions. For example, a flagger can quickly decide to stop traffic through the work zone to accommodate the work operation as necessary. Flaggers provide the most flow efficiency of all the controls. Also, the use of flaggers is very easy to implement and they can be easily removed from the work zone, as needed. The disadvantages of using flaggers include flagger fatigue and boredom, high costs, and hazards to flaggers.

The Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) provides a comprehensive guide for highway construction and maintenance work. The MUTCD is meant to be applied as a national standard and has been adopted by the state of Washington.

According to the MUTCD, "each person whose actions affect maintenance and construction zone safety - from the upper-level management personnel through construction and maintenance field personnel - should receive training appropriate to the job decisions each individual is required to make. Only those individuals who are qualified by means of adequate training in safe traffic control practices and have a basic understanding of the principles established by applicable standards and regulations, including those of the MUTCD, should supervise the selection, placement, and maintenance of traffic control devices in maintenance and construction areas."

According to the MUTCD, the following methods of signaling with sign paddles (primary signaling device) should be used:

1. "To stop traffic, the flagger faces traffic and extends, the "STOP" sign paddle in a stationary position with the arm extended horizontally away from the body," and then "motions traffic ahead with the free hand."
2. "When it is safe for traffic to proceed, the flagger faces traffic with the "SLOW" sign paddle held in a stationary position with the arm extended horizontally away from the body."
3. "To alert or slow traffic, the flagger faces traffic with the "SLOW" sign paddle, held in a stationary position with the arm extended away from the body."

The flagger is to be located far enough in advance of the worksite to give the approaching traffic sufficient distance to reduce speed before entering the work zone. This distance is related to approach speed and physical conditions at the site; however, 200 to 300 feet is desirable (according to the MUTCD). The flagger is to stand on the shoulder adjacent to the traffic being controlled or in the barricaded lane. The flagger should be clearly visible at all times.

For single lanes used by traffic in both directions for a limited distance due to construction, alternating one-way traffic movements through the construction area are coordinated so that (1) vehicles are not simultaneously moving in opposite directions and (2) delays are not excessive at either end. Alternating one-way traffic control, according to the MUTCD, may be affected by the following means:

- flagger control,
- flag-carrying or official car,
- pilot car, and
- traffic signals.

According to the Washington State Department of Transportation's (WSDOT) Design Manual, section 321.04, Traffic Control Plans (TCPs) "must be included in the PS&E (Plans, Specifications and Estimates) to provide for the orderly movement of vehicles and pedestrian traffic through construction and maintenance areas. In most instances, a reference in the plans to one or more of the TCPs shown in the Standard Plans will provide for adequate traffic control through any particular work area."

The TCPs referred to in the WSDOT Design Manual for two-lane, two-way highways when one lane is closed due to highway construction, are shown in Figures 3.1 and 3.2.

TRAFFIC SIGNALS

Traffic signals are presently used in a majority of states in the U.S. for controlling conditions of high traffic volumes, long work zones, or poor sight distances. Their use is becoming even more popular because of the availability of portable traffic signals, which cost less than standard, permanent signals (3). The costs of standard traffic signals have limited their use to specific conditions, such as lane closure work zones on restricted width bridges lasting for extended periods (4).

Portable traffic signal systems are free-standing, self-contained and easily transportable. They are designed to be adaptable to a variety of situations. Portable traffic signal systems could potentially replace flaggers at many work zones involving lane closures on two-lane, two-way roadways (3).

The advantages of using portable traffic signals in highway work zones are as follows:

1. Their operating costs are less than those for flaggers in the work zone; the cost involved is the purchase cost and maintenance (5).
2. Portable signals provide less ambiguous, more easily understandable signals to the travelling public; the problems of flagger inattention or flaggers issuing conflicting signals would be eliminated (4).

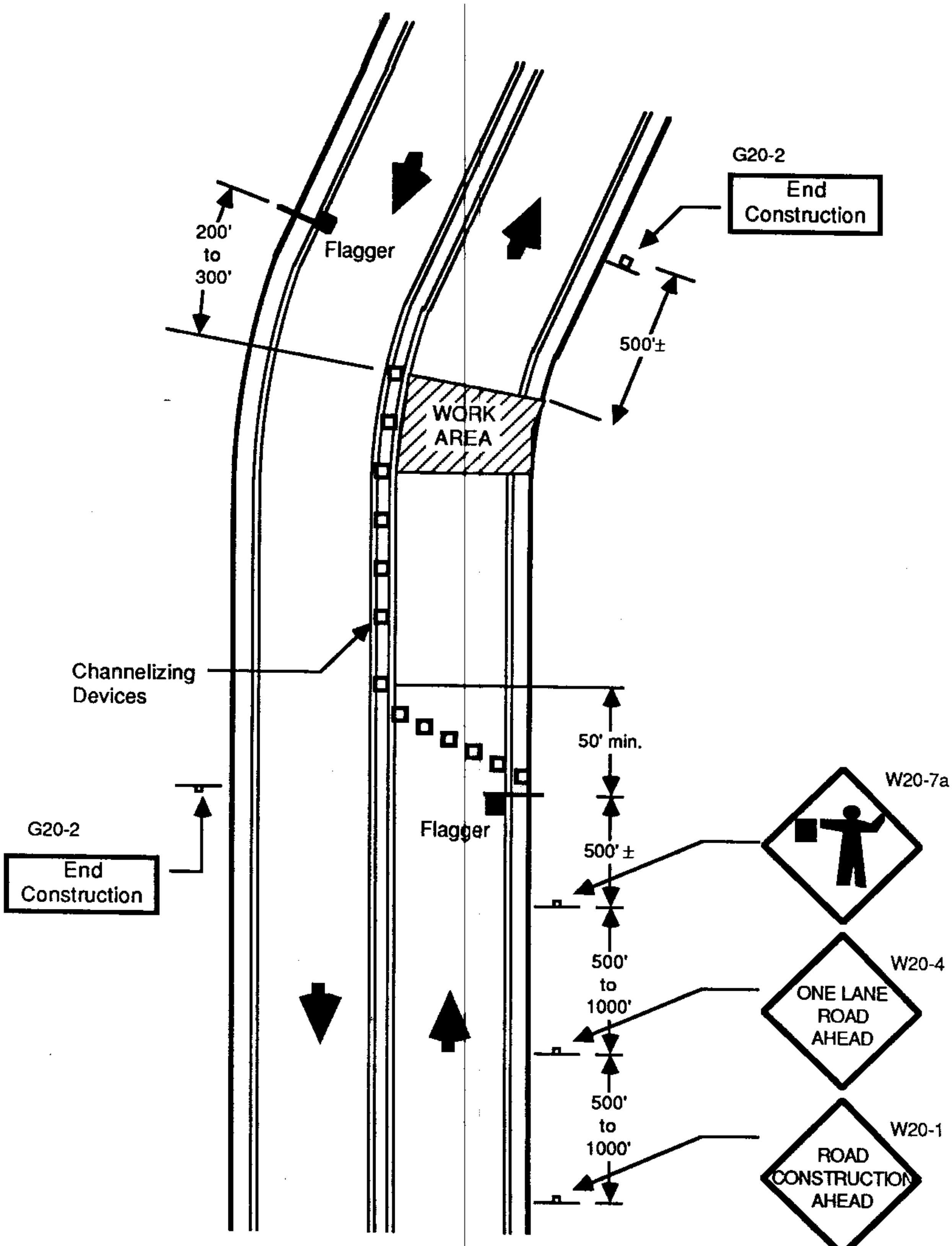

Figure 3.1. Typical Traffic Control Plan for Highway Work Zone Where One Lane is Closed and Flagging is Provided [ref. Washington State DOT]

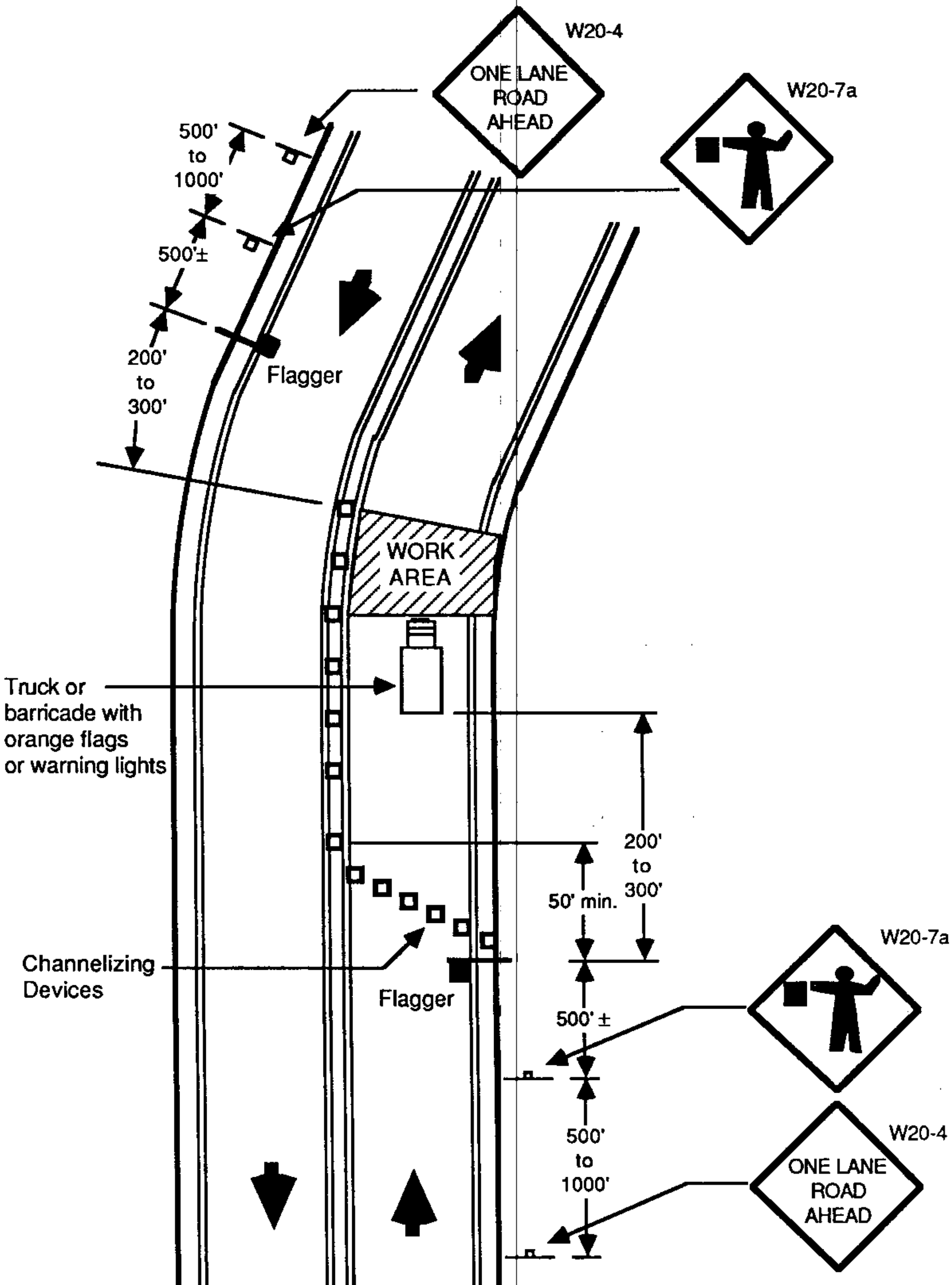

Figure 3.2. Typical Traffic Control Plan for Highway Work Zone Where One Lane is Closed and Flagging is Provided (Short duration operation only) [ref. Washington State DOT]

The disadvantages of the traffic signal use in work zones are as follows:

1. The green light gives motorists the incorrect indication that they don't have to exercise caution as they proceed through the work site.
2. When working in the fixed-time mode, the traffic signal results in longer stop delays per vehicle at the work zone than does flagger control. The increased delay is a function of the signal timing parameters - cycle length, green phase, etc.
3. In remote locations, where traffic signals are unexpected, violations tend to be slightly higher. The violations are usually a result of motorists ignoring the end of the green phase and joining the end of the platoon of vehicles traveling through the work zone. Although none of these violations have resulted in reported accidents, the potential for accidents does exist. However, the compliance rate in traffic signal control should increase as motorists become more familiar with them (4).

STOP SIGN CONTROL (4, 5)

Stop sign control at work zones requiring alternating one-way traffic control is used in at least five states in the United States: Alaska, California, Delaware, South Dakota, and Utah. This control involves the posting of stop signs on both approaches to a two-way, two-lane highway work zone where one lane is closed to traffic.

In theory, the stop sign control should provide for a safe work zone since all motorists will be required to stop in advance of the construction site. This stoppage should reduce the vehicle speeds through the construction zone. The full stop should also allow motorists to react to any emergencies or break-down in the control system.

In practice, there are many violations of the stop sign. However, most of these violations are rolling stops where the motorists are reacting, in part, to the existing traffic conditions.

In the state of California, stop signs are permitted in short work zones on rural, low volume highways with good sight distances. California requires the following sequence of signs before the stop sign: "ROAD CONSTRUCTION AHEAD," "ONE-LANE ROAD AHEAD," "STOP AHEAD," "STOP AND PROCEED WHEN CLEAR."

South Dakota uses stop sign control for roadways with traffic volumes between 600 and 1,300 vehicles per day. South Dakota requires that a portable barrier be provided when stop sign control is used. The signing sequence is similar to that in California except that a 15 mph advisory speed sign is installed between the "ONE-LANE ROAD AHEAD" sign and the "STOP AHEAD" sign. In addition, the stop sign has a high intensity flashing red light.

The advantages of the stop sign are similar to those of the traffic signals:

- operating costs are low,
- a clear, unambiguous directive is given to motorists to stop, and
- the motorists understand that caution must be exercised.

The disadvantages of stop sign use for regulating alternating traffic on two-lane, two-way highway closures are as follows:

- There is no clear indication of right-of-way for both directions of traffic. If two vehicles arrive at both stop signs simultaneously, there is no obvious way of deciding who has the right-of-way. The most decisive or bolder of the two motorists simply takes the initiative and proceeds.
- Higher stop delay times are expected, particularly if queues develop at both stop signs and one vehicle goes through at a time.

YIELD SIGN CONTROL (4)

Yield sign control at work zones where one lane of a two-way, two-lane highway is closed is used in at least six states: Alaska, Delaware, Michigan, Missouri, Nebraska and Ohio. This control involves the posting of yield signs on one or both approaches to the work zone. Where a yield sign is posted on one approach only, the assignment of right-of-way is positive and understandable. On the other hand, when posted on both sides, right-of-way assignment can be confusing to motorists approaching the work zone. The assumption made is that the closed-lane traffic will normally yield to traffic in the open lane.

The states that permit yield sign control at work zones permit them only in short zones and where good sight distances prevail. Three sets of signs are used preceding the yield sign: "ROAD

CONSTRUCTION AHEAD," "ONE-LANE AHEAD," and "WATCH FOR ONCOMING TRAFFIC." One state, South Dakota, allows yield sign control only if the traffic volume is equal to or less than 600 vehicles per day and where a portable concrete barrier around the construction site is provided.

The advantages and disadvantages are similar to those of a stop sign except that the yield sign does not attempt to bring all approaching vehicles to full stop positions. yield signs can be used in short work zones with excellent sight distance and very low traffic volumes.

CHAPTER 4
REVIEW OF FLAGGER ACCIDENTS

Flaggers may be exposed to considerable danger if improper flagging procedures are used or if a driver blatantly disregards the instructions of the flagger. The extent of this danger was examined in this study. Flagger accidents in work zones were reviewed to determine the extent of this exposure on a nationwide basis. Accident data were obtained from OSHA (Occupational Safety and Health Administration) for 32 states, the district of Columbia, and Guam. The details of the data are contained in Appendix A. Data were not available from states that have federally-monitored "State-OSHA" plans. In the six years that were evaluated, (from 1977 to 1982) 14 fatalities involved flaggers in work zones: an average of 2.3 per year. In comparison, during the four-year period from 1983 to 1986, 19 fatalities involving flaggers occurred: an average of 4.75 per year (a 106.4 percent increase). Fatality and injury information is summarized in Table 4.1.

The OSHA standards that provide guidelines for flagging operations are contained in OSHA regulation No. 1926.201 entitled "Signaling" and further subtitled, "Flagman." The OSHA flagging standards are in four parts and these are paraphrased as follows:

1. Flaggers "shall" be provided when work zone operations are such that signs, signals, and barricades do not provide necessary protection on or adjacent to a highway or street.
2. Flaggers "shall" perform their flagging duties of signaling in accordance with the Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD).
3. Flaggers "shall" use either red flags or sign paddles to perform their hand signaling tasks. In periods of darkness, red lights "shall" be used.
4. Flaggers "shall" wear red or orange warning vests while flagging. Warning vests "worn at night shall be of reflectorized material."

These subparagraphs of the OSHA flagging standard are hereafter referred to as subparagraphs 1, 2, 3, and 4. A verbatim version of the related OSHA regulation is contained in Appendix A.

Table 4.1. Summary of Flagging Related Injuries and Fatalities from 1977 to 1985 Resulting from Violations of OSHA Code 1926.201a

Subparagraph No.	Number of Non-injury/ non-fatality Violations	Percent of Violations	Number of Injuries	Percent of Injuries	Number of Fatalities	Percent of Fatalities	Total Number of Violations	Percent of Total Violations by Subparagraph No.
1	151	24.3	2	22.2	13	39.4	166	25.0
2	10	1.6	0	0	0	0	10	1.5
3	94	15.1	2	22.2	5	15.2	101	15.2
4	367	59.0	5	55.6	15	45.4	387	58.3
TOTAL	622	100.0	9	100.0	33	100.0	664	100.0

The OSHA records reviewed in this study revealed that from 1977 to 1986, 664 violations of the flagging regulation had occurred (refer to Table 4.1). Of these violations, 96.7 percent resulted in no personal injuries. Of the 664 infractions, 58.3 percent involved Subparagraph 4 (warning vests) and 25.0 percent involved Subparagraph 1 (not providing flaggers when their services would have provided the needed protection for construction workers and motorists). As would be expected, the violation of Subparagraph 4 resulted in the highest number of injuries - five (55.6 percent of the total) and the highest number of fatalities - 15 (45.4 percent of the total). Also predictably, the second most violated standard, Subparagraph 1, resulted in the second highest number of injuries - two (22.2 percent of the total) and the second highest number of fatalities - 13 (39.4 percent of the total). The remaining injuries (2) and the remaining fatalities (5) resulted from violations of Subparagraph 3.

Another interesting aspect of the data contained in Table 4.1 is that 78.9 percent of the accidents involving flaggers resulted in a fatality. This fact underscores the vulnerable position in which the flagger is placed in the event of an accident.

These violations of OSHA flagging standards represent only a fraction of the actual incidents at construction sites. However, they indicate the trends of which types of violations are taking place and the resultant severity of related accidents. Figure 4.1 indicates the trend in violations of each subparagraph. There was a noticeable drop in the number of violations of all the subparagraphs in 1979. This could have been due to reduced highway reconstruction work in that period or a reduction in safety inspections during that period. Figure 4.2 shows the trend in the relationship between violations of OSHA flagging standards and the fatalities resulting from these violations. The violations of subparagraphs 1 and 4 were consistently high compared to the violations of the other subparagraphs. The data suggest that any effort made to reduce the violations of subparagraphs 1 and 4 would tend to result in a decline of flagger related accidents. Also, Figure 4.2 indicates that the rate of flagger fatalities resulting from violations of OSHA standards is increasing. This increase in the rate of resulting fatalities suggests that more attention needs to be given to flagging safety.

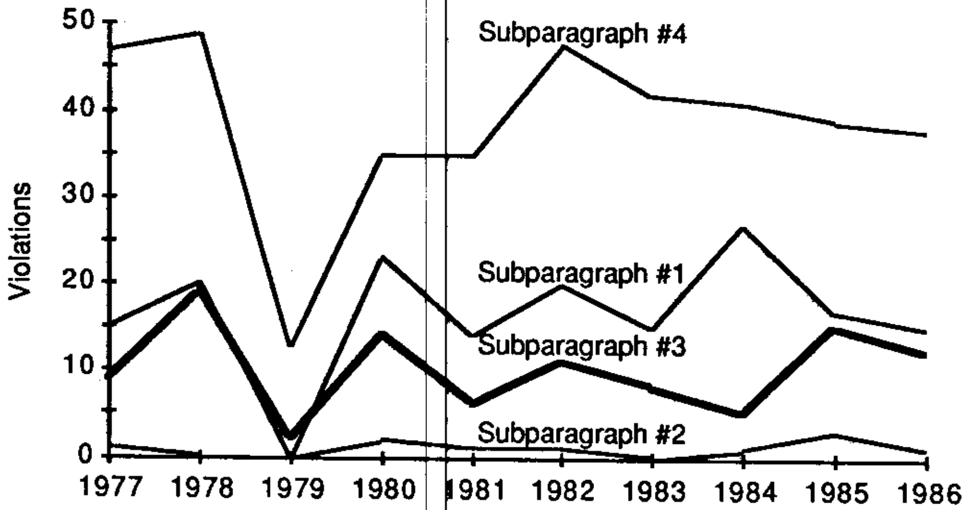

Figure 4.1. Trend in Violations of OSHA Flagging Subparagraphs

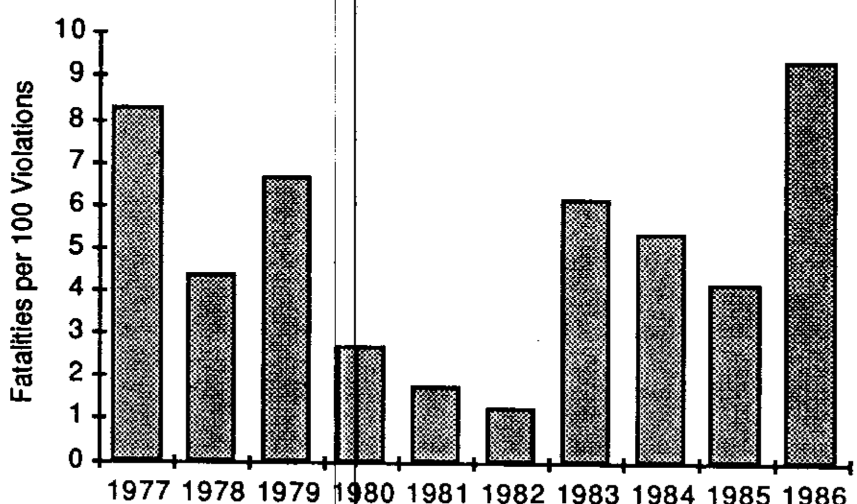

Figure 4.2. Trend in the Relationship Between Violations of OSHA Flagging Standards and Resulting Fatalities.

CHAPTER 5
SURVEY OF FLAGGERS

Although the review of accident data provided some insights on the nature of the exposure of flaggers to injury, it did not provide any detailed qualitative information about flagging. To gather this additional data, a small study was conducted to obtain information directly from flaggers. Twenty flaggers who are presently employed in the flagging profession in four Seattle-area companies were included in the survey process. These flagging companies provide flagging services for highway construction projects as well as for utility-related projects adjacent to highways. Some questions were added to the questionnaire after some interviews had been conducted. It is noted in this text when responses were not obtained from all of the twenty flaggers.

Each interview took from 15 to 30 minutes. The questions posed to the flaggers had to do with three main areas of interest to this research.

1. General information was obtained from the flaggers involved in this survey - how long they had been flaggers, why they became flaggers, and whether or not they considered their flagging job as a profession or as temporary employment.
2. Respondents were asked to describe the training they had received to prepare them for their present jobs.
3. The flaggers' experiences on highway construction work zones were sought - motorists compliance with flagger control, and the perceived or actual incidence of danger to the flagger at the work site.

GENERAL INFORMATION ON THE FLAGGERS

The 20 flaggers interviewed had been flaggers for an average of 2.91 years and had been working for their present employers for an average of 2.57 years. About 80 percent of the flaggers were still employed by the company with which they initially started flagging. About 73 percent (73.3%) of 15 respondents indicated that they became flaggers because they liked the outdoors and the flexible hours of the job. The rest of the flaggers (26.7%) of the 15 respondents became flaggers "for the money" or because their current job included some flagging. About half (52.6%) of 19 flaggers interviewed considered flagging a profession, rather than a temporary job.

TRAINING

All of the flaggers interviewed had received the minimum amount of training required to obtain a flagging certificate (a prerequisite for the flagging job). In addition, most (87.5%) of 19 flaggers interviewed had participated in additional, on-the-job training before beginning their first flagging assignment. However, a majority (83.3%) of 18 respondents felt that they had received adequate flagging training.

The following are suggestions that the flaggers gave for improving flagger training:

- Spend at least one-half day looking at different flagging situations.
- Have some different situations set up in a parking lot and go through all of the different possibilities with a new flagger before he or she is certified.
- Spend some time talking about the different flagging situations the flaggers are likely to face on the job.
- Spend at least one week in training to become a certified flagger (instead of the present one-day program).

FLAGGERS' EXPERIENCES

Eighty percent (80.0%) of the 20 flaggers interviewed had had their traffic control violated (motorists did not stop when directed to do so by the flaggers' stop sign or stop indication). However, fifty-eight percent (57.9%) of 19 flaggers indicated that motorists rarely violated their controls. Nearly a third (31.6%) of 19 flaggers indicated that motorist violations of flagger directives occurred about once a week, while 10.5 percent indicated that violations occurred about once a month.

Forty-two percent (42.1%) of 19 flaggers indicated that when the motorists violated their control, the motorists got away with it. Thirty-six percent (36.8%) of the 19 respondents said that the driver usually realized what was happening and stopped. Finally, the rest of the respondents indicated that the violating driver was involved in or was nearly involved in an accident as a result of the lack of compliance with the flagger's direction.

Almost seventy-four percent (73.7%) of 19 respondents felt they had been in danger on the job at one time or another. The dangerous situations occurred, according to the flaggers, for the following reasons:

- motorists were not paying adequate attention;
- they were working with another flagger who was inexperienced;
- motorists made deliberate maneuvers that were dangerous; and
- the weather or road conditions were bad.

Twenty percent (20%) of 15 flaggers interviewed had been hit at least once by motorists and an additional 13.3 percent had almost been hit at least once.

CHAPTER 6
FIELD DATA COLLECTION METHODOLOGY

The planned field data collection was to involve gathering data on traffic flow and traffic behavior at a construction site while control alternated weekly between flaggers, portable traffic signals, and stop signs. Yield signs were not to be included because of the limited application of this method.

For each control method used, the following on-site observations were to be recorded:

- direction of travel for each vehicle approaching the work zone,
- whether or not a stop condition was required by control,
- whether or not the approaching vehicle complied with the control,
- stopped delay time for each vehicle required to stop,
- number of vehicles in a queue,
- vehicle approach speeds and vehicle speeds through the construction zone, and
- remarks relative to driver maneuvers (e.g., actual or potential conflict situations).

To find a two-way, two-lane highway construction site where one lane was closed, a list was developed of candidate 1987 WSDOT projects that were scheduled to occur within 2 to 3 hours' drive of Seattle, Washington.

Problems with the on-site data collection procedure did not permit intensive testing of the different flagging techniques as originally planned. The main problem was the reluctance of the WSDOT districts to participate in the test. The WSDOT districts were concerned that accidents might occur as a result of the use of the proposed novel techniques (portable traffic signals, stop signs, etc.) because motorists were unfamiliar with them.

Observations planned for one site, State Route 2 (Bridges 2/38, 2/39 and 2/48 Rail Replacement in District 1) were unsuccessful because of a liability issue. Shortly before the field data were to be collected, the insurance company for the contractor refused to provide liability coverage if the portable traffic signal was used. However, traffic data were collected for flagger-only control at this site (Refer to Appendix F).

Another problem encountered in attempting to collect data was scheduling. Many of the candidate projects (two-way, two-lane highway construction projects in which one lane was closed) were not "active" during the period (May-July 1987) when the tests were to be done.

Because of the problems encountered in field testing, only a limited amount of data could be collected. Therefore, the research project was modified in scope. The new scope consisted of defining a demonstration project that the WSDOT could conduct in the future. The demonstration project would involve extensive traffic data collection on each of the flagging techniques.

Field tests of three of the flagging techniques were performed at a construction site on State Route 970, Teanaway River to SR 97/Virden. At the site, the flagger-only control was used only on the first day of work (July 13, 1987). The following day (July 14, 1987), the WSDOT field office decided to aid the flagger with a flashing red light by setting a traffic signal on its flashing red mode immediately behind the flaggers. The portable traffic signals were originally scheduled to be used on this construction project as manually-operated traffic control devices. However the signals malfunctioned (skipped a phase every fifth cycle). As a result, the signal in flashing red mode was used to supplement flagger control. This control was used for the remainder of the construction effort except for a period of 20 minutes on the morning of August 5, 1987, when a stop sign control was used. The stop sign control was used for only 20 minutes because WSDOT field office personnel felt that project safety was being compromised.

The vehicle approach speeds were recorded for vehicles approaching at about 2,500 feet ahead of the work zone in each direction. The speeds through the construction zone were recorded at locations approximately in the middle of the work zone. Electronic speed measuring devices (GK 6000 classifier/speed recorders - solid state with memory modules) were used to get the speed data. These speed recorders were used in lieu of radar guns because of their increased accuracy and reduced need for supervision.

In addition, on-site observations were made two hours a day during the study.

SITE DESCRIPTION

The three controls (flagger only, flagger aided by flashing red light and stop sign) were evaluated at a work zone location on a two-lane, two-way rural highway near Cle Elum, Washington. At this location, a lane was closed to traffic and flaggers were used to alternate one-way traffic through the work zone. The site was a fairly level section of highway and on a tangent section. The westbound approach to the work zone was on a 2,865 foot radius curve that became a tangent section 1,500 feet before the work zone and was on a 0.22 percent descending grade. The eastbound approach to the work zone was a tangent section on a 1.66 percent ascending grade. There was virtually no commercial development in the general area of the construction site.

The 1986 Average Daily Traffic (ADT) at this site was 1,950, of which 24 percent was truck traffic. At the work zone, approximately 820 feet of one-directional lane was closed in order to correct bridge deficiencies on the Teanaway River bridge located at the site. Flaggers with two-way radios were used at the ends of the work zone to alternate traffic through the one-lane section.

Advance signing at the approaches to the work zone consisted of the following signs: "ROAD CONSTRUCTION AHEAD," "ONE LANE AHEAD," and "FLAGGER AHEAD" or "STOP AHEAD." The signs were spaced approximately 500 feet apart.

DATA COLLECTION AND ANALYSIS

The three different controls examined during this field study for both directions of travel through the work site were as follows:

1. Control by flagger only consisted of the standard MUTCD set-up, with flaggers using only standard stop/slow signs and hand signals to communicate with approaching vehicles (see Figure 6.1, Traffic Control Plan Used for "Flagger Only" Controlled Two-Lane Highway Zone).

2. The flagger aided with a flashing red light was the same as the flagger only set-up, with the addition of a flashing red light (portable traffic signal in flashing red mode)

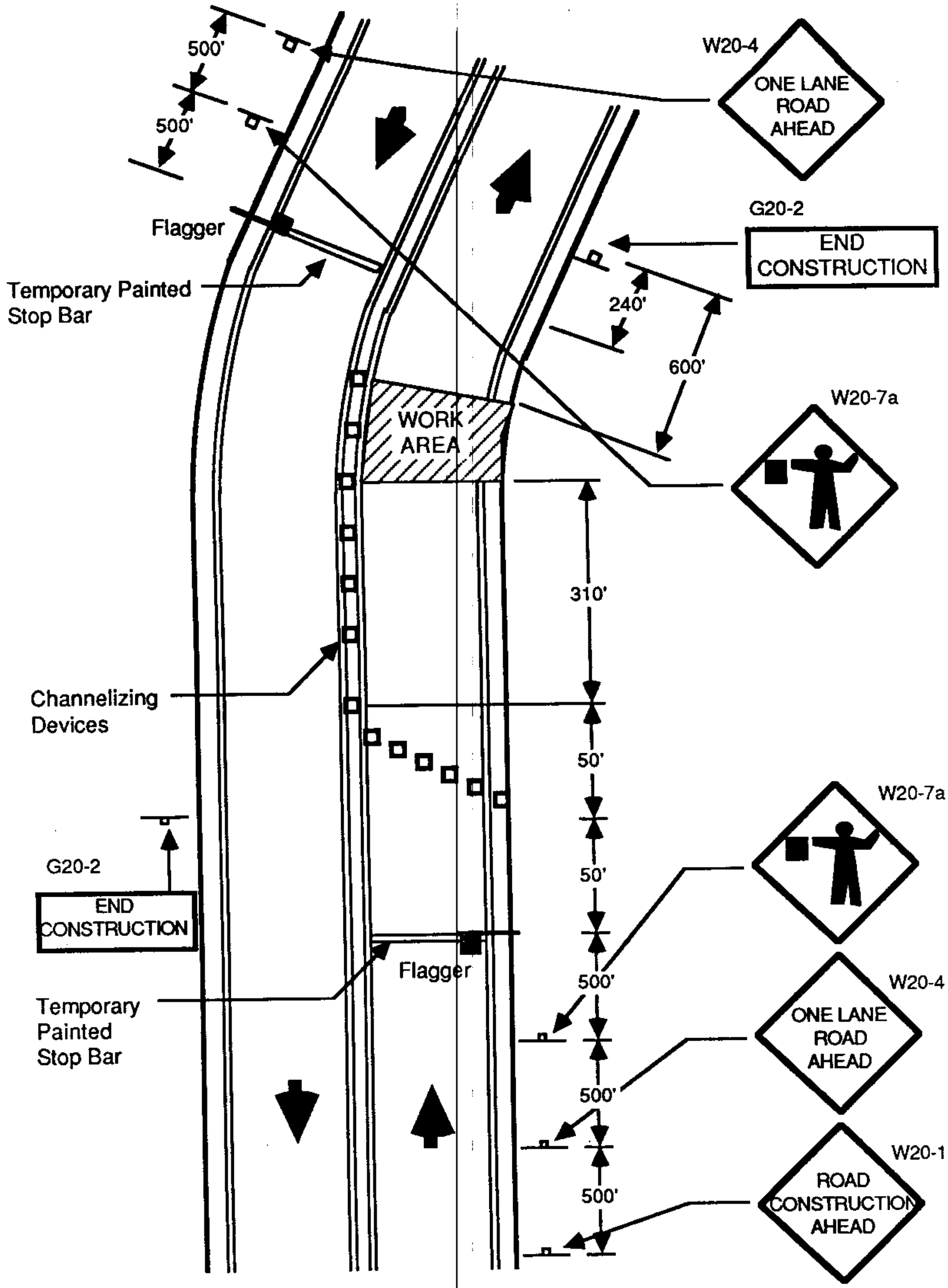

Figure 6.1. Traffic Control Plan Used for "Flagger Only" Controlled Two-Lane Highway Zone

(see Figure 6.2, Traffic Control Plan Used for "Flagger Aided with Flashing Red Light" Controlled Two-Lane Highway Zone).

3. Control by stop sign consisted of a standard stop sign supplemented by another sign on the same post with the message, "One Lane Road Ahead Proceed With Caution When Clear." The portable traffic signal in flashing red mode was also placed behind the stop sign (see Figure 6.3, Traffic Control Plan Used for Stop Sign Controlled Two-Lane Highway Work Zone).

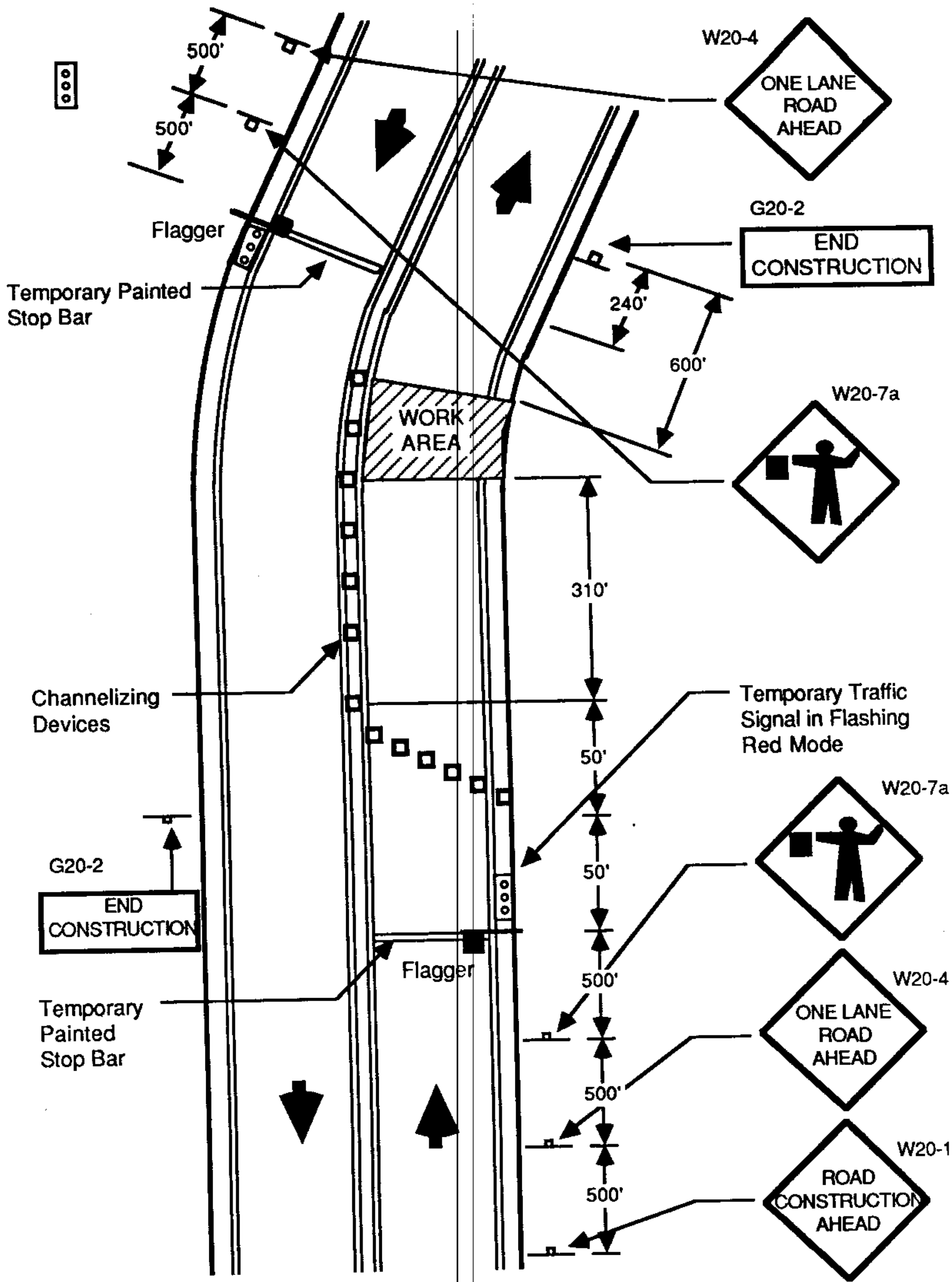

Figure 6.2. Traffic Control Plan Used for Flagger Aided with Flashing Red Light Controlled Two-Lane Highway Work Zone

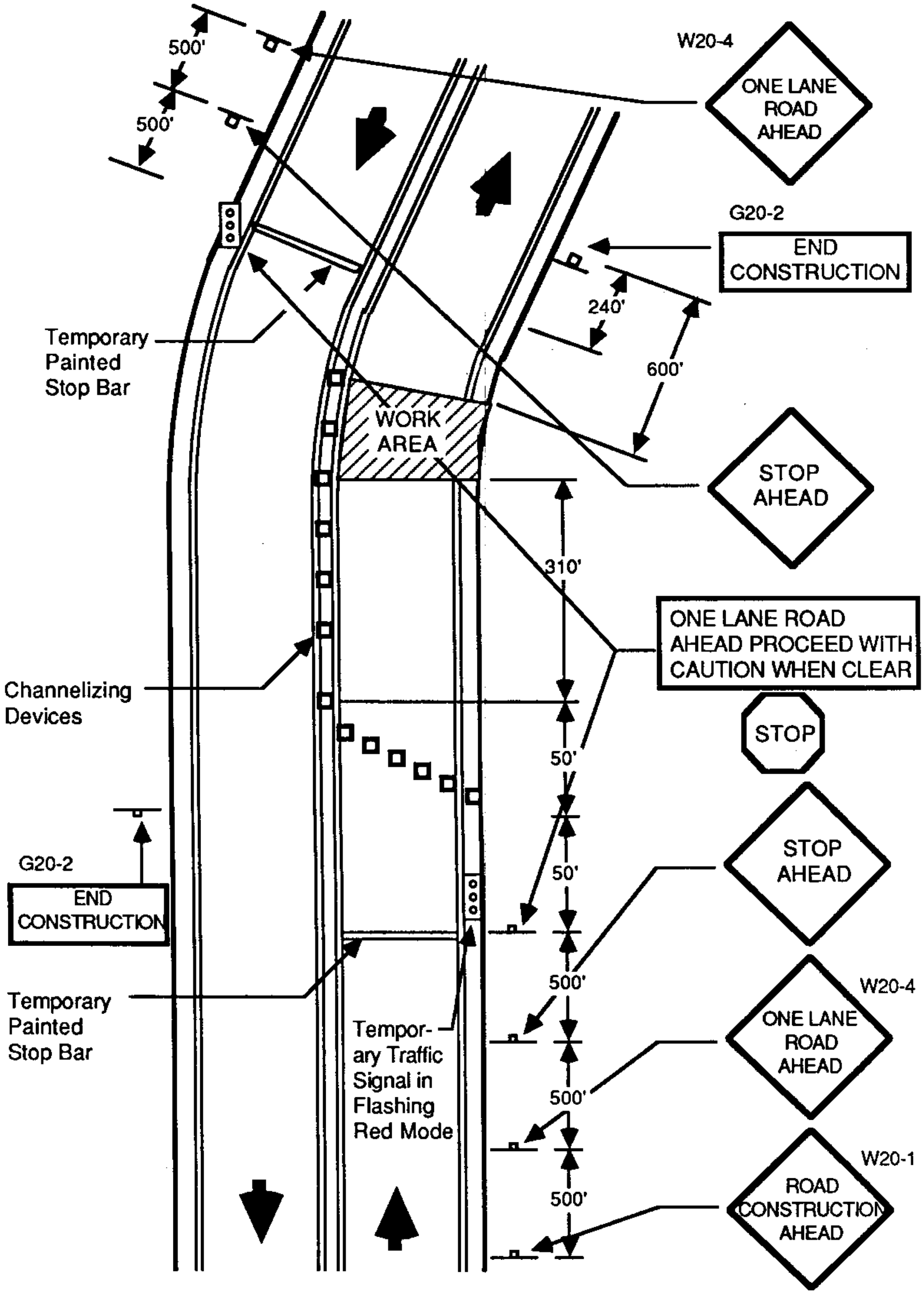

Figure 6.3. Traffic Control Plan Used for Stop Sign Controlled Two-Lane Highway Work Zone

CHAPTER 7
DATA COLLECTION RESULTS

A total of 522 vehicles were observed at the location. Table 7.1 gives the general conditions that existed during the data collection period. The results of the data collection are as follows:

1. For eastbound traffic through the work zone, the average size of a queue created by flagger only control was 2.29 vehicles while that created by a flagger aided with a flashing red light was 1.78 (see table 7.2 and 7.3). The average queue size when eastbound traffic was controlled by stop sign (aided with a flashing red light) was 1.82 vehicles. The rest of the queue size data are contained in Appendix C. The data suggest that the queue size, when the eastbound traffic was controlled by flagger only, was not significantly different from the queue size when traffic was controlled by the flagger or stop sign, both aided with a flashing red light.

2. Fifty percent of both eastbound and westbound vehicles arriving at the work zone experienced no delay when traffic was controlled by flagger only (see Table 7.4). When both eastbound and westbound traffic were controlled by flaggers aided with the flashing red light, an average of 75.4 percent arriving at the work zone experienced no delay. Under stop sign control, an average of 7.1 percent of both eastbound and westbound traffic experienced no delay. The average delay per approach vehicle was 27 seconds when traffic was controlled by flagger only, 72 seconds when controlled by stop sign, and 22 seconds when controlled by a flagger aided with a flashing red. The summary of the stopped delay data is contained in Table 7.4.

   The limited data available suggest that aiding the flagger with a flashing red light increases the percentage of vehicles experiencing no delay and reduces the average

TABLE 7.1
CONDITIONS UNDER WHICH TRAFFIC DATA WERE COLLECTED FOR EACH CONTROL

1. QUEUE SIZE AND STOP DELAY DATA

	Flagger Only Control	Flagger Aided with Flashing Red Light	Stop Sign Control
Time	9:14 am - 11:14 am	11:34 am - 1:34 am	7:46 am - 8:26 am
Day	July 13, 1987 (Monday)	July 14, 1987 (Tuesday)	August 5, 1987 (Wednesday)
Weather Conditions	Clear, Sunny, Warm, High winds (80°F)	Clear, Sunny Warm (90°F)	Clear, Sunny, Mild (60°F)

2. SPEED DATA

	Before Construction Speed Data	Flagger Only Controlled Work Zone	Flagger Aided with Flashing Red Light Controlled Work Zone Data
Day	July 7, 1987 (Tuesday)	July 7, 1987 (Monday)	July 14, 1987 (Tuesday)
Time	12:00 a.m. - 12:00 p.m. (midnight to noon)	12:00 a.m. - 12:00 p.m. (midnight to noon)	12:00 a.m. - 12:00 p.m. (midnight to noon)
Weather Condition	Temp. 50+ - 90+F	50+ - 90+F	50+ - 90+F

TABLE 7.2
QUEUE SIZE DATA FOR EASTBOUND TRAFFIC[1]

	Flagger Only Control	Flagger Aided with Flashing Red Light	Stop Sign Control
Total observation time (Hr)	2	2	0.33
Total vehicles per hour	64	87	99
Average queue size	2.29	1.79	1.82
% of Vehicles in 5 - vehicle or less queues	87.1	100.0	84.5

TABLE 7.3
QUEUE SIZE DATA FOR WESTBOUND TRAFFIC[1]

	Flagger Only Control	Flagger Aided with Flashing Red Light	Stop Sign Control
Total observation time (hr)	2	2	0.33
Total vehicles per hour	54	74	132
Average queue size	2.04	2.00	2.00
% of Vehicles in 5 - vehicle or less queues	83.7	75.0	79.2

[1]Refer to Table 7.1 for field test conditions.

TABLE 7.4
STOP DELAY DATA[1]

und	Flagger Only Control		Flagger Control Aided with Flashing Red Light		Stop Sign Control	
	Eastbound Traffic	Westbound Traffic	Eastbound Traffic	Westbound Traffic	Eastbound Traffic	Westbo Traffic
Sample Size	122	107	174	147	33	24
% of vehicles that experienced no stop delay	47.5	54.2	89.1	59.2	6.1	8.3
Average Stop Delay for Stopped Vehicles Only	54	47	52	66	35.6	192.6
Average Stop Delay for All Vehicles	28	21	18	27	30.2	128.4

delay per approaching vehicle. They further suggest that the stop delay increases appreciably when work zone traffic is controlled by a stop sign.

The benefit of reduced motorist delay at the site offsets the additional cost of providing flashing red lights.

3. Average eastbound approach speeds for vehicles about 2,500 feet in advance of the work zone were reduced by 1.7 mph for the flagger only control and 2.4 mph for flagger control aided with a flashing red light (see Table 7.5 through 7.11 and Figure 7.1 through 7.3). The average westbound approach vehicle speed was reduced by 13.2 mph for the flagger only control and 13.6 mph for the flagger control aided with a flashing red light.

[1]Refer to Table 7.1 for field test conditions.

TABLE 7.5
SPEED REDUCTION VARIATIONS WITH TRAFFIC CONTROL METHOD*[1]

	Flagger Only Control	Flagger Aided with Flashing Red Light
Reduction in average approach speed (eastbound) (mph)	1.7	2.4
Reduction in average approach speed (westbound) (mph)	13.2	13.6
Reduction in average speed through construction zone (both directions) (mph)	28.9	29.9

TABLE 7.6
EASTBOUND APPROACH SPEEDS TO CONSTRUCTION ZONE*[1]

(mph)	Before Construction (mph)	Flagger Controlled Construction Zone (mph)	Flagger Control Aided with "Flashing Red" Traffic Signal
Average speed	57.4	55.7	55.0
Median speed	57.6	56.3	56.6
85% tile speed	63.1	62.0	61.7

*Speed data for stop sign control could not be measured because the speed measuring device used lists measured speeds by hour only. Stop sign was used for only 20 minutes.

[1]Refer to Table 7.1 for field test conditions.

*Speed data for stop sign control could not be measured because of limited time (20 minutes) when stop sign was used. The speed measuring device used only lists speeds by the hour.

TABLE 7.7
REDUCTIONS IN EASTBOUND APPROACH SPEEDS TO CONSTRUCTION ZONE*[1]

	Flagger Controlled Construction Zone	Flagger Control Aided with "Flashing Red" traffic signal (mph)
Average speed	1.7	2.4
Median speed	1.3	1.0
85% tile speed	1.1	1.4

TABLE 7.8
WESTBOUND APPROACH SPEED TO CONSTRUCTION ZONE*[1]

	Before Construction (mph)	Flagger Control Only (mph)	Flagger Control Aided with "Flashing Red "Traffic Signal (mph)
Average speed	57.6	44.4	44.0
Median speed	58.3	44.8	44.8
85% tile speed	64.8	53.7	52.8

TABLE 7.9
REDUCTIONS IN WESTBOUND APPROACH SPEEDS TO CONSTRUCTION ZONE*[1]

	Flagger Control Only (mph)	Flagger Control Aided with "Flashing Red" traffic Signal (mph)
Average speed	13.2	13.6
Median speed	12.5	13.5
85% tile speed	11.1	12.0

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*Speed data for stop sign control could not be measured because of limited time (20 minutes) when stop sign was used. The speed measuring device used only lists speeds by the hour.

[1]Refer to Table 7.1 for field test conditions.

TABLE 7.10
SPEEDS THROUGH THE CONSTRUCTION ZONE
(BOTH DIRECTIONS)*[1]

	Before Construction (mph)	Flagger Controlled Construction Zone (mph)	Flagger Control Aided with "Flashing Red" Traffic Signal (mph)
Average speed	57.5	28.6	27.6
Median speed	57.9	28.5	27.7
85%tile speed	63.9	34.6	33.7

TABLE 7.11
REDUCTIONS IN SPEED THROUGH THE CONSTRUCTION ZONE
(BOTH DIRECTIONS)[1]

	Flagger Control Only (mph)	Flagger Control Aided with "Flashing Red" traffic Signal (mph)
Average speed	28.9	29.9
Median speed	29.4	30.2
85%tile speed	29.3	30.2

*Speed data for stop sign control could not be measured because of limited time (20 minutes) when stop sign was used. The speed measuring device used only lists speeds by the hour.

[1]Refer to Table 7.1 for field test conditions.

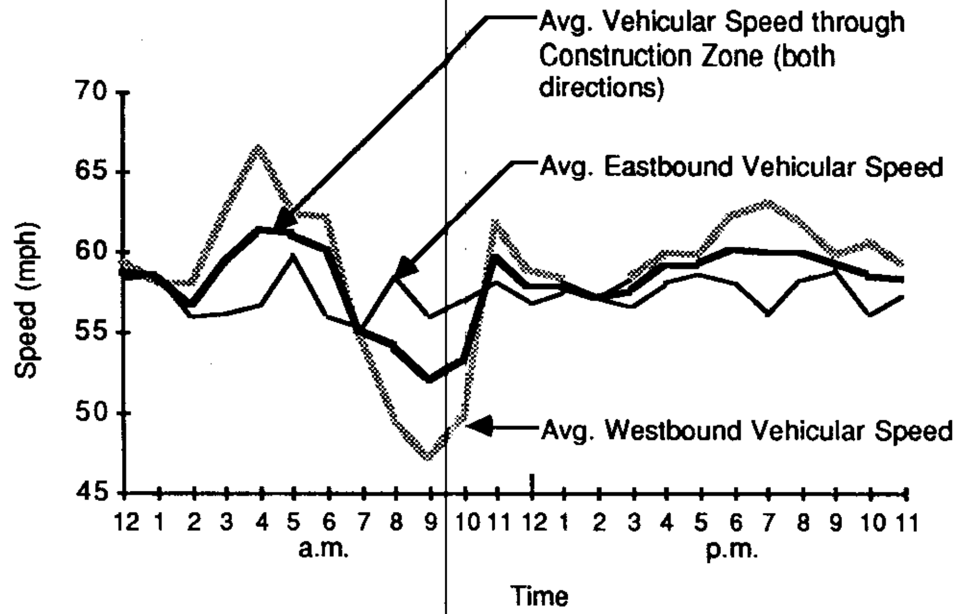

Figure 7.1. Traffic Speeds Before Start of Construction

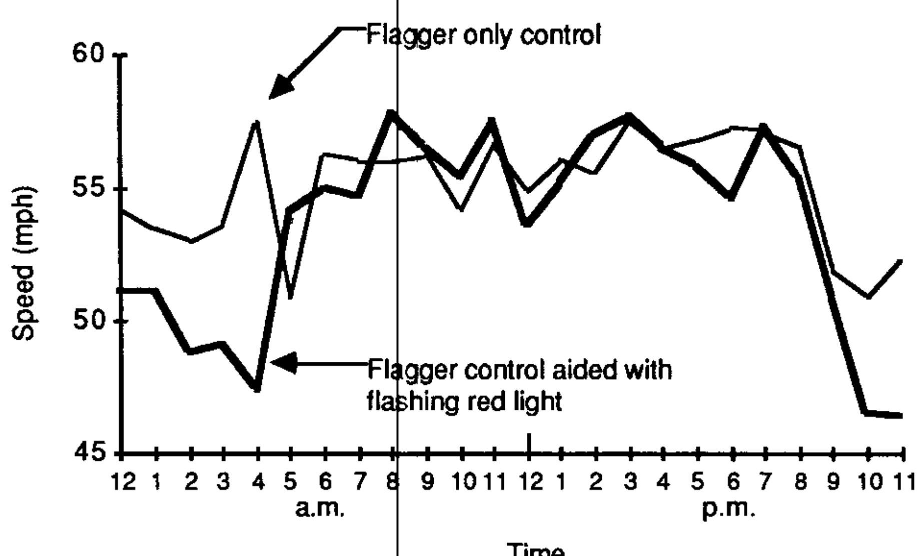

Figure 7.2. Comparison of Average Eastbound Approach Speeds for Flagger Only Control and for Flagger Aided with Flashing Red Light Control

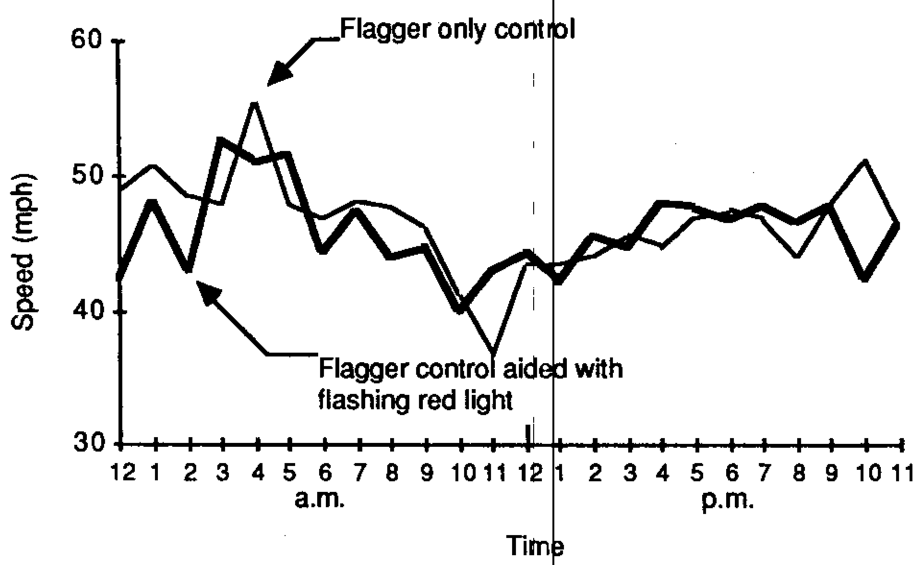

Figure 7.3. Comparison of Average Westbound Approach Speeds for Flagger Only Control and for Flagger Aided with Flashing Red Light Control

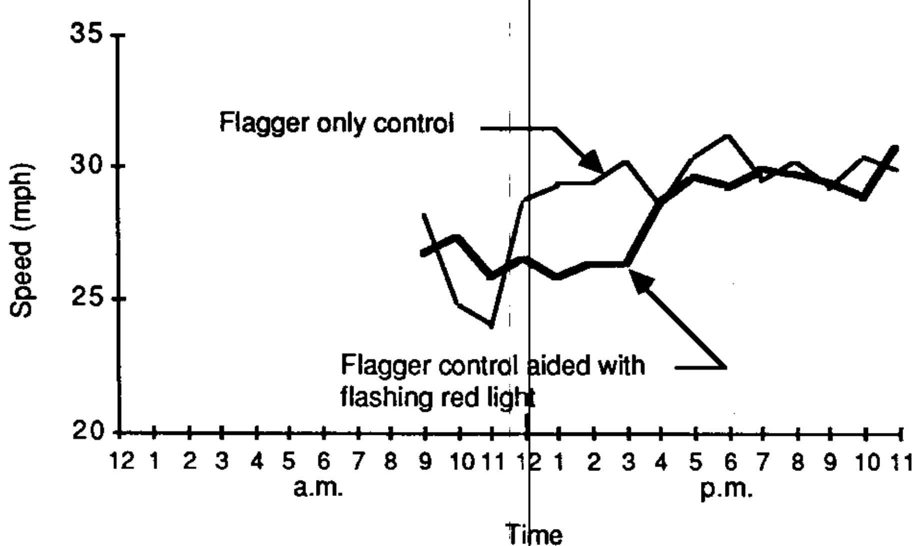

Figure 7.4. Comparison of Average Vehicular Speeds (Both Directions) for Flagger Only Control and for Flagger Aided with Flashing Red Light Control

The limited data available suggest that aiding the flagger with a flashing red light improves the effectiveness of the flagger in reducing vehicle approach speeds. The flashing red light makes the construction zone more conspicuous to motorists during the day and at night, thereby causing them to reduce their speeds earlier than when the traffic is controlled by the unaided flagger.

The westbound approach vehicle speeds were reduced by a wider margin than those for the eastbound approach. A probable explanation for this is that the sight distance on the westbound approach (in excess of 5,000 feet) was better than the eastbound approach (about 2,000 feet). The construction area was more visible to westbound motorists at further distances and therefore they were able to react earlier, resulting in greater speed reductions.

When compared to pre-construction speeds, the average vehicle speed through the construction zone was reduced by 28.9 mph for the flagger only control and 29.9 mph for flagger control aided with a flashing red light. This difference in speed was found to be significant at the 95 percent confidence level (see Appendix E).

The data suggest that aiding the flagger with a flashing red light decreases the vehicle speeds through the construction zone more than the unaided flagger control. The flashing red light tended to convince the motorists of the need to proceed with caution through the work zone. Such a speed reduction should reduce accident potential at the work zones.

DRIVER BEHAVIOR AND COMPLIANCE

Virtually none of the motorists observed at the construction site had any problems understanding what was required of them as they proceeded through the work zone. Of the 211 vehicles observed for the flagger only control, only two (approximately 0.9 percent) were driven erratically. One of them (an eastbound motorist) actually violated the flagger's directive to stop.

Fortunately, the incident did not end in an accident. The other incident involved a westbound motorist who had difficulty stopping at the stopline indicated by the flagger and ended up stopping about 20 feet beyond the flagger station and had to back up.

Of the 321 vehicles observed while traffic was controlled by flaggers aided with flashing red lights, no vehicles were driven erratically. This indicates that motorists take more care when the work zone open lane is controlled by a flagger aided with a flashing red light.

CONCLUSION

The results of the field study were used in evaluating the three different flagging techniques. On the basis of these limited results, the flashing red lights appear to be effective devices in helping motorists proceed through the work zone in a safer manner, as exhibited by

- reduced motorist delays,
- reduced vehicle approach speeds,
- reduced vehicle speeds through the construction zone, and
- reduced erratic driver behavior exhibited at work zones.

The stop sign used in the work zone showed some potential for being effective in controlling traffic on two-lane highway construction zones when one lane is closed. However, more data are needed to make any definite conclusions.

CHAPTER 8
DESIGN OF PILOT PROJECT FOR THE EVALUATION OF ONE-LANE TRAFFIC CONTROL METHODS

THE EVALUATION PROCESS

The evaluation of alternative actions/methods is a means by which all the benefits, costs, and impacts of each action or method is considered in order to contribute to the judgment of its relative merits. The approach taken in this study is that of an evaluation process (the interaction among key participants) as opposed to an evaluation technique. The reason for this is that the issues at stake in this study are as much political as they are technical in nature. This report entails a careful consideration of the impacts of different methods of construction zone traffic control. All of the methods were previously field tested.

In developing an overall framework for the evaluation of the different alternatives for controlling vehicular traffic through two-way two-lane highways when one of the lanes is closed, the following six fundamental guidelines were considered:

1. Focus on the decision to be made and the key issues being faced. The nature of the decision to be made determines the evaluation criteria used, and the scope and the scale of the evaluation analysis. This evaluation process is to be used in choosing the most effective method of traffic control among the various methods. The existing method is flagger control, used in conjunction with a supplemental set of devices, channelization cones and construction signs. The supplemental devices will remain constant for the different alternates.
2. Relate the consequences of alternatives to goals and objectives. The objectives emanating from the goal of this study relate to a wide set of issues (efficiency, safety, and costs). This calls for an evaluation process that can deal with the qualitative and quantitative information required.
3. Determine how particular interests are affected by the various alternatives. The traffic control method chosen will affect different groups differently. The most obvious group are the motorists.

4. Be sensitive to the time frame in which impacts are to occur. The time stream of benefits and costs is different for the alternative traffic control methods. Therefore, the evaluation process to be used has to involve an explicit documentation of the tradeoffs made between present expenditures and future net benefits and between present benefits and future costs. Because of the high levels of uncertainty involved in some of the data, the evaluation process also should be able to document these, as well as handle sensitivity analysis in an adequate way.

5. Analyze the implementation requirements of each alternative. The implementation of each of the traffic control alternatives requires the use of different resources of funding, labor, construction capability, and engineering and design expertise. The evaluation process used must be able to explicitly consider these factors so that the results emerging from this study are feasible.

6. Provide information on the value of each alternative in a readily understandable form. Because most of the decision-makers that will be using the information have limited time and patience to consider the tradeoffs that were made between alternatives, the evaluation process used should highlight these tradeoffs and the values upon which these tradeoffs were made.

The six guidelines discussed above imply an evaluation process that provides involvement for interested parties, summarizes in understandable terms the key issues to be considered, and guides much of the technical analysis process. A framework that has the characteristics discussed above is the Goals Achievement Matrix. The Goals Achievement Matrix evaluation method investigates a number of alternatives in the light of multiple criteria and conflicting priorities. This evaluation approach consists of (at least) a two-dimensional matrix, where one dimension expresses the various alternatives and the other dimension expresses the criteria or measures of effectiveness (MOEs) by which the alternatives are to be evaluated.

GOALS ACHIEVEMENT MATRIX EVALUATION METHOD (9)

The following steps were used in the study to apply the Goals Achievement Matrix evaluation method:

1. Identify and describe the goal(s) and related objectives for the study. As used in this report, goals are generalized statements that broadly relate to the desired end but for which no test for fulfillment can be readily applied. Objectives, on the other hand, are specific, measurable statements of policy related to the attainment of the goals.

2. Determine alternatives. The alternatives used in this study had the following characteristics:

   - they were a means of achieving the goals defined;
   - they were feasible to implement financially, legally, and politically;
   - the relative performances of the alternatives varied in range. This was to permit a more comprehensive analysis.

3. Design measures of effectiveness or criteria for each objective. These are measures or tests that reflect the degree of attainment of particular objectives.

4. Estimate the performance of each alternative using the measures of effectiveness developed in Step 2 by means of "raw" criteria scores. These scores reflect the degree to which an alternative meets a certain criterion. The determination of "raw" criteria scores depends greatly on the type of evaluation problem and the way this problem can be treated. According to Voogd (10), the yardstick by which the value of an alternative should be determined is based on the best available information. In this study, only direct quantitative determination of scores were made. The scores were derived from a combination of observed characteristics as well as intuitive estimation by the author. A possible problem of double counting is taken care of in the prioritization or weighing of the criteria.

5. Standardize "raw" criterion scores. This involves the process of transforming the scales used for the various measures to a new common scale to make the various criteria scores compatible. This transformation is known as standardization. The

kind of standardization used in this study is one that in the opinion of the author produces the least mathematically distorted result and is represented by the following equation:

$$\text{standardized score } i = \frac{\text{raw score } i - \text{min. raw score}}{\text{max. raw score} - \text{min. raw score}} \qquad \text{(Eq. 10.1)}$$

For some of the criteria, a higher criteria "raw" score implied a better score, whereas for others, the higher score implied a worse score. The standardized scores for the first kind was produced by equation 10.1. The standardized scores for the second kind were calculated by subtracting the result of Equation 1 from one.

6. Develop weights for objectives. Normally, weights for the various objectives would be determined by asking groups that would be potentially affected to weigh the relative importance of each objective. However, in this study the weights were arrived at judgmentally as time pressures did not permit conducting a survey. The affected groups that were identified in this study included

   - motorists,
   - flaggers,
   - other construction workers, and
   - state department of transportation officials.

   Each group hypothetically distributed points among the different criteria, thereby reflecting the relative importance of each criterion to each group in accordance with the author's judgment of what the point distribution would be in an actual survey. All the weights were listed in columns.

7. Summarize the scores for each alternative by multiplying the standardized scores for each alternative by the respective weight, and adding the products for each alternative.

8. Interpret the results of the analysis. The traffic control alternative with the largest overall, weighted score was the most desirable based on the analysis. Next, the relative sizes of the scores were examined and all the values used in the preceding

analysis were reviewed to determine why the resulting ranking of alternatives occurred the way it did.

EVALUATION GOAL AND OBJECTIVES

The goal of this study is to improve the effectiveness of traffic control in a two-way, two-lane highway construction zone when one lane is closed. The following objectives logically follow from the stated goal and were confirmed from the literature:

- minimize travel time through the work zone,
- maximize safety for motorists and construction workers,
- maximize efficiency in moving vehicular traffic through the construction zone,
- minimize vehicular operating cost,
- minimize capital cost of control, and
- minimize the economic impact on the flagging personnel.

ALTERNATIVES

The following list of alternative methods of traffic control through work zones was developed after their contribution to the evaluation goal, their feasibility of implementation and their range was considered:

- flagger control using standard equipment (stop/slow paddle),
- portable traffic signal with fixed time setting,
- portable traffic signal with full traffic-actuated setting,
- portable traffic signal with manually-actuated setting, and
- stop sign control.

Flagger control using standard equipment (Alternative A) involves flaggers using an 18-inches by 18-inches "stop /slow" sign (sometimes called a "paddle") to control traffic. The flagger's main position is on the shoulder of the road, just outside the right lane, i.e., about 3 to 4 feet from the edge of the pavement.

The portable traffic signal control involves the use of traffic signals that are easy to move around. This control is used to replace flaggers on both ends of the closed lane in a two-lane, two-way highway situation. Portable traffic signals can be used in basically two modes - in fixed time mode (Alternative B) or traffic-actuated mode (Alternative C). It can be electronically actuated (Alternative C) or done manually by an operator (Alternative D).

Stop Signs

Alternative E involves the use of stop signs on both approaches to the construction area. All motorists approaching the work zone stop before the zone, which reduces their speeds through the construction area. However, this alternative is restricted to short work zones and low volume highways because of the potential of conflicts.

CRITERIA FOR OR MEASURES OF EFFECTIVENESS

The following characteristics were considered in deciding the criteria for judging the effectiveness of each of the alternatives:

1. The criteria must be relevant to the issue of choosing the best traffic control mechanism for use in two-lane, two-way highways.
2. The criteria must be measurable.
3. Costs for data collection and analysis must be commensurate with the value of the information produced.
4. The criteria must be specific at a level of detail appropriate for the decision to be made, as must its sensitivity to change.
5. They must be applicable to a wide range of alternatives.
6. The criteria must represent a manageable number of measures not so many that they overwhelm the decision makers involved.
7. They must be understandable.

The objectives considered important in this evaluation and their related measures of effectiveness are listed below:

Objective	Measures of Effectiveness
Minimize Travel Time	a. Average number of stops per vehicle (fewer is better)
	b. Average vehicle delay time per stop (less is better)

Objective		Measures of Effectiveness
Maximize Safety	c.	Non-compliance rate (less is better)
	d.	Speed through work zone (mph) (less is better)
Maximize Efficiency	e.	Average length of queue per hour (less is better)
Minimize Vehicular Costs	f.	Operating and maintenance cost ($) (less is better)
Minimize Capital Costs	g.	Capital cost ($) (less is better)
Minimize Economic Impact	h.	Number of employee positions eliminated per construction project (less is better)

PERFORMANCE OF EACH ALTERNATIVE

The data contained in Table 8.1, which formed the core upon which the performance of the five alternative traffic control methods were evaluated, were estimated from experience with data collection on this research project. Table 8.1 contains the hypothetical "raw" performance scores for the various alternatives. The cost of flagger control is the wages paid (including fringe benefits and travel) :

Annual cost of flagger control = 2(flaggers)X$10(per hr.)X8(hrs per day)X20(days per mo.)X3(mo. per yr.)

=$9600 per year

Present worth of the cost for flagger control=

9600((1+.05)10-1)/.05/(1+.05)10) for discount rate of 5% and period of 10 years*

= $74,129.

*10 year analysis period is assumed

Present worth of the cost for manually-actuated signal control

= 1/2 X $74,129 + $15,000(cost of the signal)

= $52,064

Further assumptions were made in computing cost, including equating to zero the maintenance and operating cost of the stop sign, the fixed-time portable traffic signal, and the

TABLE 8.1
"RAW" PERFORMANCE SCORES

OBJ/ALT	A	B	C	D	E
a	130.00	260.00	130.00	130.00	860.00
b	2.50	24.00	3.00	3.00	12.00
c	0.05	0.01	0.05	0.05	0.14
d	22.50	22.50	25.00	20.00	20.00
e	1.50	1.80	1.50	1.50	1.50
f	74,000.00	15,000.00	20,000.00	52,000.00	100.00
g	0.00	2.00	2.00	1.00	2.00

where

Alternative A: Flagger control using standard equipment (stop/slow paddle)

Alternative B: Portable Traffic Signal with fixed time setting

Alternative C: Portable Traffic Signal in traffic actuated mode

Alternative D: Portable Traffic Signal With Manual Control

Alternative E: Stop sign control

Criteria "a": Average number of vehicle stops per vehicle

Criteria "b": Average Vehicle Delay per stop (seconds)

Criteria "c": Non-compliance Rate

Criteria "d": Speed through work zone (mph)

Criteria "e": Average Length of (Number of vehicles in) queue per hour

Criteria "f": Capital, Operating and Maintenance Cost ($)

Criteria "g": # of jobs eliminated per construction project

TABLE 8.2
STANDARDIZED SCORES

OBJ/ALT	A	B	C	D	E
a	1.00	0.82	1.00	1.00	0.00
b	1.00	0.00	0.98	0.98	0.56
c	0.69	1.00	0.69	0.69	0.00
d	0.50	0.50	0.00	1.00	1.00
e	1.00	0.00	1.00	1.00	1.00
f	0.00	0.80	0.73	0.30	1.00
g	1.00	0.00	0.00	0.50	0.00
TOTAL	5.19	3.12	4.40	5.47	3.56
RANKING	2	5	3	1	4

electronically controlled, traffic activated signal. Listed below are the "raw" performance scores that were used in this study:

STANDARDIZED PERFORMANCE SCORES

Table 8.3 contains the standardized scores that result from measuring the various alternatives with the criteria for effectiveness. The standardized scores resulting from the "more-is-better" criteria were obtained from Equation 1. On the other hand, the standardized scores resulting from the "less-is-better" criteria were obtained by subtracting the results of Equation 1 from one. The sum of the standardized scores for each alternative represents its value without weighting. The score summation indicates that alternative D (manually-operated actuated signal) had the highest total score.

WEIGHTS

Listed below are the point distributions given by the four hypothetical rating groups for each criterion.

The weights are not dramatically high for any one criterion. The author tried to mirror reality as much as possible. The weights for criteria "a" and "b" represent over 40 percent of the total weights on the average. This is compatible with most drivers' attitudes toward travel time (the author was a highway flagger at various locations in western Washington for three months).

If some big changes were made to the weights, the resulting order of the alternatives would change. Another possibility considered was adjusting the weights to reflect the percent of citizens in each of the groups. The author decided against that, since that would have adversely affected the input of the flaggers who, although a small percentage of the driver population, are most vulnerable to the impacts of change in traffic conditions because of their exposure.

PERFORMANCE SCORE SUMMARY

Shown on the next three pages are the score summaries resulting from the evaluation process. Tables 8.4 through 8.7 show the standardized scores different driver groups. The figure entitled "Total Weighted Standardized Scores By Alternates" illustrates how each traffic control method was rated

TABLE 8.3
WEIGHTS FOR EACH GROUP

	Motorists	Flaggers	Other Construction Workers	State Department of Transportation Officials
a	30	20	15	21.7
b	30	20	15	21.7
c	5	10	15	10
d	5	10	15	10
e	10	10	10	10
f	10	15	15	13.3
g	10	15	15	13.3
Total	100	100	100	100.0

Where

Criteria "a": Average number of vehicle stops per vehicle (Less is better)

Criteria "b": Average Vehicle Delay per stop (seconds) (Less is better)

Criteria "c": Non-compliance Rate (Less is better)

Criteria "d": Speed through work zone (mph) (Less is better)

Criteria "e": Average Length of queue per hour (Less is better)

Criteria "f": Capital, Operating and Maintenance Cost ($) (Less is better)

Criteria "g": # of jobs eliminated per construction project (Less is better)

TABLE 8.4
WEIGHTED, STANDARDIZED SCORES
USING WEIGHTS FOR MOTORISTS

	WEIGHT	A	B	C	D	E
a	30.00	30.00	24.60	30.00	30.00	0.00
b	30.00	30.00	0.00	29.40	29.40	16.80
c	5.00	3.45	5.00	3.45	3.45	0.00
d	5.00	2.50	2.50	0.00	5.00	5.00
e	10.00	10.00	0.00	10.00	10.00	10.00
f	10.00	0.00	8.00	7.30	3.00	10.00
g	10.00	10.00	0.00	0.00	5.00	0.00
Total	100.00	85.95	40.10	80.15	85.85	41.80
Ranking		1	5	3	2	4

TABLE 8.5
WEIGHTED, STANDARDIZED SCORES
USING WEIGHTS FOR FLAGGERS

	WEIGHT	A	B	C	D	E
a	20.00	20.00	16.40	20.00	20.00	0.00
b	20.00	20.00	0.00	19.60	19.60	11.20
c	10.00	6.90	10.00	6.90	6.90	0.00
d	10.00	5.00	5.00	0.00	10.00	10.00
e	10.00	10.00	0.00	10.00	10.00	10.00
f	15.00	0.00	12.00	10.95	4.50	15.00
g	15.00	15.00	0.00	0.00	7.50	0.00
Total	100.00	76.90	43.40	67.45	78.50	46.20
Ranking		2	5	3	1	4

TABLE 8.6
WEIGHTED, STANDARDIZED SCORES
USING WEIGHTS FOR OTHER CONSTRUCTION WORKERS

	WEIGHT	A	B	C	D	E
a	15.00	15.00	12.30	15.00	15.00	0.00
b	15.00	15.00	0.00	14.70	14.70	8.40
c	15.00	10.35	15.00	10.35	10.35	0.00
d	15.00	7.50	7.50	0.00	15.00	15.00
e	10.00	10.00	0.00	10.00	10.00	10.00
f	15.00	0.00	12.00	10.95	4.50	15.00
g	15.00	15.00	0.00	0.00	7.50	0.00
Total	100.00	72.85	46.80	61.00	77.05	48.40
Ranking		2	5	3	1	4

TABLE 8.7
WEIGHTED, STANDARDIZED SCORES FOR STATE DOT OFFICIALS

AVE.WEIGHT	A	B	C	D	E
21.70	21.70	17.79	21.70	21.70	0.00
21.70	21.70	0.00	21.27	21.27	12.15
10.00	6.90	10.00	6.90	6.90	0.00
10.00	5.00	5.00	0.00	10.00	10.00
10.00	10.00	0.00	10.00	10.00	10.00
13.30	0.00	10.64	9.71	3.99	13.30
13.30	13.30	0.00	0.00	6.65	0.00
100.00	78.60	43.43	69.57	80.51	45.45
	2	5	3	1	4

with the different weight sets. In almost all the cases, alternative D, with or without the weights, appears to be the superior alternative.

ANALYSIS OF RESULTS

Each of the alternatives exhibited different strengths and weaknesses. The final ranking of the alternatives resulted from a summation of the scores in attaining the goals of the evaluation process.

Alternative A (Flagger control). This alternative did well in decreasing travel time, delay, queue length, and economic impact and increasing compliance rate, but did poorly in decreasing operating cost.

Alternative B (Portable traffic signal with fixed timing). This alternative increased the compliance rate and decreased cost but did poorly in decreasing travel time, delay, queue length, and economic impact.

Alternative C (Portable traffic signal with traffic actuated-control). This alternative decreased travel time, delay, and queue length, but did poorly in decreasing compliance rate and decreasing operating cost and economic impact.

Alternative D (Portable traffic signal with manually-controlled timing). This alternative did well in decreasing travel time, delay, and economic impact but did poorly in decreasing queue length and operating cost.

Alternative E (Stop sign control). This alternative decreased operating cost and economic impact but did poorly in increasing the compliance rate and decreasing travel time, delay, and queue length. In all the cases but one, Alternative D (operator-actuated portable traffic signal) appeared to be the superior alternative. Alternative A (flagger control) was second in each case but one. Alternative A would have been evaluated higher than alternative D if the weight applied to criterion "b" had been increased to 30 percent and the weights of the other criteria had been reduced correspondingly. With the high weight for vehicle delay time, the position of alternative D was relatively secure.

SENSITIVITY ANALYSIS

Although, alternative D proved to be the most superior alternative in three of the four cases, alternative A was superior to alternative D for two criteria, b and g. Alternative A was the only viable alternative capable of beating alternative D for the performance scores used.

CONCLUSION

From this evaluation, it appears that alternative D (the operator-actuated portable traffic signal), was the best in satisfying the identified criteria and the affected groups, in spite of the fact that the stop sign had the advantage of low capital, operation, and maintenance costs. However, although the results may be counter-intuitive, they are logical. The operator-actuated portable signal incorporates the values of the traditional flagging operation and the high tech portable traffic signal.

Before a definite conclusion can be reached, the assumed "raw" performance values and weights should be verified. A final decision should be delayed until a more thorough data verification is done.

CHAPTER 9
SAMPLE SPECIAL PROVISION FOR USE IN DEMONSTRATION PROJECT -- TEMPORARY TRAFFIC SIGNALS

The purpose of the sample "Special Provision" for the demonstration project is to provide guidance for setting up contract specifications for temporary traffic signals.

DESCRIPTION

The work under this item shall consist of furnishing, installing, and maintaining a temporary portable traffic signal installation at the locations shown on the project plans and in accordance with the requirements of the specifications and these special provisions.

The minimum number of single indications shall be as shown on the project plans.

The system shall include the following:

1. A 110 V.A.C. diesel generator with fuel capacity to operate a minimum of 72 hours. The generator shall be securely mounted on one of the signal controller trailers in an enclosed lockable wire cage.

   The generator shall be equipped with a regulator to regulate the voltage at 110 V.A.C. 60 Hz. regardless of engine speed.

2. A 12-foot minimum mast arm assembly with a 15-foot vertical minimum clearance shall be attached to the trailer, if the mast arm assembly is provided.

3. Each signal controller trailer unit shall have two signal heads. Each traffic signal head shall have a 12-inch red, 8-inch yellow, and 8-inch green light. Each trailer assembly shall have a signal head mounted at the end of the mast arm, and also a signal head shall be mounted on the top of the vertical mast arm support.

   Signal circuit conductors shall be run unspliced from the controller cabinet (or the terminal box on the remote trailer unit) to the terminal connector strip at the side mounted signal head. Quick disconnect connectors shall not be used. The signal circuit cables on each trailer shall be type TC-THWN, AWG #14, 4 conductor, stranded, sun resistant, rated for direct burial, 600 Volt, and UL listed.

4. The traffic controller assembly shall meet the requirements of NEMA and the 1985 Supplemental Specifications. A two-phase, NEMA Solid State DAN-2 controller shall be mounted on one of the trailers in an enclosed, lockable Type II, NEMA 3 weather resistant cabinet, per TS 3-10. The controller shall operate it as a two-phase, fully-actuated unit, and it shall have the capability of being manually operated to display simultaneous red on both phases. The all-red clearance timing shall be approved by the Engineer. A manual pushbutton with a minimum 12-foot coil cord shall be furnished and wired to the controller.

   Flaggers shall be used to control traffic during the startup of the signal system and at any time in which mode changes occur (such as from automatic to manual or vice versa). Flaggers shall also be used for traffic control at any time during construction for public safety as required by the Engineer.

   In the flash mode, the controller shall flash red to both phases.

5. Each of the traffic signal trailer units shall be set up on the shoulder of the roadway behind the guard rail and shall be leveled and secured as directed by the Engineer in the field. Each trailer unit shall be secured by removal of the trailer tongue to prevent tampering. Both trailer units shall be grounded by installation of a 10-foot, copper plated grounding rod at each site.

6. The UF cables connecting the two traffic signal trailers shall be UL listed. Routing, burial, and installation of the UF cables shall be as directed by the Engineer in the field.

7. The loop detectors required by the plans shall be temporary loops preformed at the factory. Contractor assembly shall <u>not</u> be asphalt backing to bond to asphalt pavement. The loop wires shall be sandwiched between two 2-inch wide, high density

polyethelene film strips. The bottom strip shall have a very adhesive bituminous rubber compound for bonding to asphalt roadway surfaces. The top layer of the loop detector sandwich system shall be a 4-inch wide strip of woven polypropylene mesh with the same bonding compound described above.

The loop detector shall have 15 feet of lead-in conductor, 5 feet of which shall be protected with the same sandwiched components as the loop.

The nominal width of the system shall be 4 inches, with a nominal maximum height of 0.194 inch tapering to 0.064 inch at the edges.

The loop detector system shall have three turns of type B-MIL-W-16878-Vinyl 600 V.-105 degree 22 gauge wire with 7 x 30 gauge strands.

The loop detectors shall be installed as shown on the plans or as directed by the Engineer in the field.

CONSTRUCTION REQUIREMENTS

At the preconstruction conference the contractor shall submit the type of equipment being proposed for use for approval by the Engineer.

After written approval has been issued by WSDOT, the contractor shall install temporary signals as required to meet the construction schedule. The contractor shall notify the Engineer at least 48 hours in advance of when the temporary signal installation is ready to be turned on. Upon approval of the installation by the Engineer, the maintenance of the temporary signal installation, including all fuel charges, shall become the responsibility of the contractor until removal is directed by the Engineer. The contractor shall be responsible for maintaining the signals in proper operating condition. Any damage to the temporary traffic signal installation from any cause whatsoever shall be repaired by and at the expense of the contractor. If, at any time, the contractor fails to perform any work deemed necessary by the Engineer to keep the temporary traffic signals in proper operating condition, the

Engineer may have others perform the needed work. The cost of such work will be deducted from the amount due to the contractor.

The phase timings utilized to control traffic shall be as approved by the Engineer. All phase timing shall be determined and put into the controller by Traffic Operations personnel. The signal shall be initially turned on by Traffic Operations personnel.

When the signal installation is not in operation, the signal heads shall be taken down.

BASIS OF PAYMENT

Payment for this work will be made at the contract lump sum price bid for TEMPORARY TRAFFIC SIGNALS, the price of which shall be full compensation for the complete item, including maintenance, energy costs and removal when directed by the Engineer, all as described and specified herein and on the project plans.

CHAPTER 10
PROPOSED GUIDELINES FOR FIELD TESTING THE RECOMMENDED FLAGGING TECHNIQUE IN A DEMONSTRATION PROJECT

As discussed in Chapter 6, Data Collection, problems with time constraints, liability issues, and equipment failure limited the field testing to one of the flagging techniques being considered. The flagging techniques or methods identified in addition to MUTCD flagging in this study are as follows:

1. flagger control aided with flashing red lights (field tested),
2. fixed time traffic signal,
3. traffic-actuated traffic signal,
4. manually-operated traffic signal,
5. stop sign, and
6. yield sign.

CHARACTERISTICS OF CANDIDATE DEMONSTRATION PROJECTS

The type of highway construction project chosen for this demonstration should be one in which flagger control is needed. The demonstration project should be one that involves the control of alternating, one-way traffic through a one-lane work zone on a two-lane, two-way highway. In addition, the highway on which the construction work is being performed should have an average of no more than 600 to 1,300 equivalent passenger cars per day. Experience on this research project indicated that this limit is realistic. As the traffic volumes become higher, some of the controls (e.g., the stop sign) become less effective. Also, the highway should have sufficient sight distance to (1) permit motorists to see the presence of a flagging device and be able to bring their vehicles from the speed limit to a complete stop at the specified stop line and (2) permit motorists to see the other control device at the other approach to the work zone once they are stopped.

TRAFFIC CONTROL PLANS

The largest work zone to be considered should be similar to that contained in the Washington State Department of Transportation's Standard Plan - K-1 and K-2 (Figures 3.1 and 3.2). For traffic signal control, the "Flagger Ahead" sign is replaced by a "Signal Ahead" sign and a temporary painted stop bar is installed 50 feet before the traffic signal. The stop sign controls are similar to that of traffic signal control except that the "Signal Ahead" sign is replaced with a "Stop Ahead" sign. In addition, the stop sign should have the following attachments:

1. a sign with the message "One Lane Ahead, Proceed with Caution when Clear," and
2. a flashing red light.

The signs for the yield sign control should be similar to those used for stop sign control except that the "Stop Ahead" is replaced with "Yield Ahead" and the stop sign replaced by a yield sign.

DATA COLLECTION AND ANALYSIS

The procedures for collecting and analyzing data should be similar to those discussed in Chapter 6, Field Data Collection, and Chapter 7, Data Collection Results. The following data and information should be gathered and analyzed for each control:

1. average stop delay per vehicle,
2. average queue length per vehicle,
3. average approach speed reduction per vehicle,
4. average reduction in speed through the construction zone,
5. compliance rate,
6. number of incidents of erratic driver behavior per vehicle, and
7. general observation of the work zone.

A method to enhance an unbiased evaluation of the alternative flagging methods is covered in Chapter 8. Contained in Chapter 9 is a sample special provision for "Temporary Traffic Signals."

CHAPTER 11
CONCLUSIONS AND RECOMMENDATIONS

The traffic control provided by flaggers at the observed one-lane construction zone appeared to be adequate. While the construction was observed, no significant operational problems were noted. Virtually all of the motorists who passed through the site proceeded at a reasonable manner with a minimum amount of delay.

The traffic control (flagging) provided at the site appeared to be adequate for the particular combination of traffic volume and construction zone length.

In addition, a minimal amount of erratic driving behavior was exhibited, indicating that motorists were able to understand the control signals and to adjust their driving accordingly. Flaggers perform some duties that none of the alternative devices could perform, for example, (1) giving the motorists special instructions for driving through the work zone, and (2) improving driver awareness of warning signs. However, the potential for harm to flaggers makes it necessary to consider ways to improve the awareness of motorists so that they recognize the need to exercise caution. The use of a flashing red light helps the motorist to approach the work zone and proceed through it at a slower speed, thereby potentially improving the safety of the flagger.

It was not possible to field test three other candidate methods for controlling alternating traffic in one-lane construction zones because of time constraints, liability issues and equipment problems. These three candidate traffic controls were a traffic signal, stop sign, and yield sign. However, a literature search regarding these controls indicated that two of the more common types of traffic control at one-lane construction sites are flaggers and traffic signals. Very few states use stop signs and yield signs on approaches to one-lane construction sites, and most of the states that use traffic signals use the fixed-time equipment. However, the traffic-actuated traffic signals would be more effective, especially in rural settings where demand varies considerably.

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APPENDIX A
FLAGGER ACCIDENTS RELATED TO VIOLATIONS OF STANDARDS

APPENDIX A
FLAGGER ACCIDENTS RELATED TO VIOLATIONS OF STANDARDS

OSHA RULES AND REGULATIONS PERTAINING TO FLAGGING (1926.201(A))

1. When operations are such that signs, signals, and barricades do not provide the necessary protection on or adjacent to a highway or street, flagmen or other appropriate traffic controls shall be provided.
2. Signaling directions by flagmen shall conform to American National Standards Institute D6.1-1971, Manual on Uniform Traffic Control Devices for Streets and Highways.
3. Hand signaling by flagmen shall be by use of red flags at least 18 inches square or sign paddles, and in periods of darkness, red lights.
4. Flagmen shall be provided with and shall wear a red or orange warning garment while flagging. Warning garments worn at night shall be of reflectorized material.

Table A.1. Number of Violations Occurring Each Year in the State of Washington with Respect to the Standard Violated and Type of Inspection (Random, Injury, Fatality)

Year	Standard	Number of Random	Number of Injuries	Number of Fatalities	Total Number of Violations
1977	1	12	0	3	15
	2	1	0	0	1
	3	9	0	0	9
	4	41	3	3	47
1978	1	19	0	1	20
	2	0	0	0	0
	3	18	1	0	19
	4	46	1	2	49
1979	1	0	0	0	0
	2	0	0	0	0
	3	1	0	1	2
	4	13	0	0	13
1980	1	23	0	0	23
	2	2	0	0	2
	3	13	0	1	14
	4	34	0	1	35
1981	1	13	0	1	14
	2	1	0	0	1
	3	6	0	0	6
	4	35	0	0	35
1982	1	20	0	0	20
	2	1	0	0	1
	3	10	1	0	11
	4	46	1	1	48
1983	1	12	1	2	15
	2	0	0	0	0
	3	8	0	0	8
	4	38	0	4	42

Table A.1. (cont.)

State	Standard	Number of Random	Number of Injuries	Number of Fatalities	Total Number of Violations
1984	1	25	0	2	27
	2	1	0	0	1
	3	4	0	1	5
	4	40	0	1	41
1985	1	14	1	2	17
	2	3	0	0	3
	3	15	0	0	15
	4	38	0	1	39
1986	1	13	0	2	15
	2	1	0	0	1
	3	10	0	2	12
	4	36	0	2	38

Table A.2 Number of Serious Violations Incurred by Each State (1977 - 86) with Respect to Standard Violated and Type of Inspection (Random, Injury, Fatality)

Note: Data reflect information obtained from all states with federal OSHA enforcement jurisdiction, Federal Trust Territories, District of Columbia, and those State-Plan states providing this information to OSHA.

State	Standard	Number of Random	Number of Injuries	Number of Fatalities	Total Number of Violations
Alabama	1	3	0	0	3
	2	0	0	0	0
	3	0	0	0	0
	4	7	0	1	8
Arkansas	1	0	0	0	0
	2	0	0	0	0
	3	1	0	0	1
	4	4	0	0	4
Alaska	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
	4	1	0	0	1
Arizona	1	1	0	0	1
	2	0	0	0	0
	3	0	0	0	0
	4	1	0	0	1
Colorado	1	1	0	0	1
	2	0	0	0	0
	3	2	0	0	2
	4	4	0	0	4
Connecticut	1	1	0	0	1
	2	0	0	0	0
	3	3	0	0	3
	4	4	0	0	4

Table A.2 (cont.)

State	Standard	Number of Random	Number of Injuries	Number of Fatalities	Total Number of Violations
District of Columbia	1	1	0	0	1
	2	0	0	0	0
	3	12	0	0	12
	4	19	0	0	19
Delaware	1	1	0	0	1
	2	0	0	0	0
	3	0	0	0	0
	4	0	0	0	0
Florida	1	9	0	0	9
	2	0	0	0	0
	3	2	0	2	4
	4	16	0	2	18
Georgia	1	0	0	1	1
	2	0	0	0	0
	3	2	0	0	2
	4	7	0	0	7
Guam	1	1	0	0	1
	2	0	0	0	0
	3	0	0	0	0
	4	6	0	1	7
Idaho	1	5	0	0	5
	2	0	0	0	0
	3	2	0	0	2
	4	4	0	0	4
Illinois	1	22	0	2	24
	2	4	0	0	4
	3	9	0	1	10
	4	43	0	2	45

Table A.2 (cont.)

State	Standard	Number of Random	Number of Injuries	Number of Fatalities	Total Number of Violations
Indiana	1	1	0	0	1
	2	0	0	0	0
	3	2	0	0	2
	4	1	0	0	1
Kentucky	1	1	0	0	1
	2	0	0	0	0
	3	0	0	0	0
	4	0	0	0	0
Louisiana	1	2	0	1	3
	2	1	0	0	1
	3	0	1	0	1
	4	2	1	0	3
Massachusetts	1	4	0	0	4
	2	0	0	0	0
	3	1	0	0	1
	4	1	0	0	1
Maine	1	1	0	0	1
	2	0	0	0	0
	3	3	0	0	3
	4	12	0	0	12
Missouri	1	0	0	0	0
	2	0	0	0	0
	3	1	0	0	1
	4	8	1	2	11
Mississippi	1	1	0	1	2
	2	0	0	0	0
	3	3	0	0	3
	4	9	0	0	9

Table A.2 (cont.)

State	Standard	Number of Random	Number of Injuries	Number of Fatalities	Total Number of Violations
North Dakota	1	1	0	0	1
	2	0	0	0	0
	3	0	0	0	0
	4	0	0	0	0
New Hampshire	1	1	0	0	1
	2	0	0	0	0
	3	1	0	0	1
	4	4	0	0	4
New Jersey	1	10	0	0	10
	2	0	0	0	0
	3	6	0	0	6
	4	19	0	0	19
New York	1	45	0	0	45
	2	1	0	0	1
	3	24	0	0	24
	4	68	0	2	70
Ohio	1	8	0	1	9
	2	1	0	0	1
	3	7	0	0	7
	4	38	0	2	40
Oklahoma	1	2	1	1	4
	2	0	0	0	0
	3	0	0	0	0
	4	0	0	0	0
Pennsylvania	1	18	0	0	18
	2	1	0	0	1
	3	6	1	1	8
	4	35	1	1	37

Table A.2 (cont.)

State	Standard	Number of Random	Number of Injuries	Number of Fatalities	Total Number of Violations
Rhode Island	1	2	0	0	2
	2	0	0	0	0
	3	0	0	0	0
	4	0	0	0	0
South Dakota	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
	4	1	0	0	1
Tennessee	1	0	0	0	0
	2	0	0	0	0
	3	0	0	0	0
	4	1	0	0	1
Texas	1	5	1	4	10
	2	0	0	0	0
	3	2	0	0	2
	4	18	0	2	20
Virginia	1	0	0	0	0
	2	1	0	0	1
	3	1	0	0	1
	4	3	1	0	4
Wisconsin	1	4	0	2	6
	2	0	0	0	0
	3	5	0	0	5
	4	23	1	0	24
West Virginia	1	0	0	0	0
	2	1	0	0	1
	3	0	0	0	0
	4	8	0	0	8

APPENDIX B
FLAGGER SURVEY RESULTS

APPENDIX B
FLAGGER SURVEY RESULTS

Summary of Flagger Interviews

1. <u>How long have you been a flagger?</u>

Average:	2.91 years
Longest:	8 years
Shortest:	3 weeks

2. <u>How long have you worked for the present company?</u>

Average of 2.57 years with same company. Less than 20 percent have changed flagging companies.

A. <u>What did you do before?</u>

Four worked for different flagging companies, three were students.

The rest were:
- nursing home attendant
- worker at a tax company
- bartender
- police officer
- secretary
- bookkeeper
- electronics worker
- housewife
- worker in marker research
- hairdresser
- orthopedic assistant
- farmer
- cannery worker
- clerk
- printer

3. <u>Why did you decide to become a flagperson?</u>

Seventy-three percent (73%) said it was because they liked the outdoors and the flexible hours. Nine percent (9%) said it was because someone recommended the job to them. Nine percent (9%) said it was because their current job included some flagging. Nine percent (9%) said it was for the money.

4. <u>Do you consider your job a profession or a temporary job?</u>

52.2 percent consider it a profession, 43.5 percent consider it a temporary job and 4.4 percent don't know.

5. <u>What kind of training have you had?</u>

Seventy-four percent had a "supervisor who held the sign and explained situations" to them (on the road training), 13 percent had some verbal training by a foreman on the job and 13 percent had "no training besides the flagging certificate training."

A. <u>Do you feel this training is adequate?</u>

Eighty-three percent felt that this was adequate training for them.
Seventeen percent felt that they needed more training.

B. <u>What do you feel could be added to the training program?</u>

Some suggestions were:

I. "Have at least one-half day looking at and discussing different situations."

II. "Have some different situations set up in a parking lot and go through all of the different possibilities with the new flaggers before they get their certificate."

III. "Just talking about the different situations should help."

IV. "Have at least one week of training with different situations before you go out on a real job."

6. <u>Do you feel that you are respected by other construction workers?</u>

Ninety-one percent felt that they were respected by the construction workers and nine percent said that it depends on the company.

A. <u>By the motorists?</u>

Forty-eight percent felt they were
Seventeen percent said no!!!
Thirty percent said they weren't as respectful
Five percent said it depended on the driver

7. <u>Has your flagging ever been ignored?</u>

Eighty three said yes and 17 percent said no.

A. <u>If it has, about how often?</u>

Fifty-eight percent said it rarely happened
Ten percent said about "once per month"
Thirty-two percent said often, "at least once per week"

B. <u>When they did run the sign, what usually happened?</u>

Forty-two percent said the driver gets away with it without the occurrence of any serious accidents.
Thirty-eight percent said that soon the driver realizes what is happening and stops.
Twenty-one percent said that the driver is or is almost involved in an accident.

8. <u>Have you ever felt that you were in danger on the job?</u>

Seventy-four percent said "yes" and 26 percent said "no."

A. Some reasons flaggers felt they were in danger were:

"The driver was not paying attention, did not slow down in time."
"When you are working with an inexperienced flagger."
"A man deliberately tried to hit me."
"A car flipped right in front of me."
"It was rainy and slick."
"A driver was coming right at us, we had to jump out of the way."

9. <u>Have you ever been hit or almost hit?</u>

Twenty-two percent had been hit, 17 percent were almost hit and 13 percent were almost hit at least once.

A. <u>What were the circumstances?</u>

"It was an accident" (mirror hit her hand).
"It was deliberate."
"It was an accident" (she cracked an elbow).
"People come right up to you and push you out of the way with their bumper."
"Cars wouldn't slow down, had to jump out of the way."
"I (the flagger) wasn't paying attention and I was almost hit."

10. <u>Have you ever been in a situation where perhaps a mechanical flagging device may have been better than having a flagperson there?</u>

Sixty-five percent said "no," 4 percent said "yes," and 31 percent said "maybe."

A. <u>Some comments were:</u>

"It might keep the flagger out of danger."
"A mechanical flagger doesn't seem practical in most situations."
"Maybe on freeways, bridges, and sharp corners."
"Maybe for just slowing down traffic."

11. <u>Do you think motorists would respect a mechanical flagging device?</u>

Twenty-two percent said "yes," 65 percent said "no," and 13 percent said "maybe."

12. <u>Do you think any flagging practices should be changed?</u>

Twenty-two percent said "yes" and 78 percent said "no."

A. <u>What should be changed?</u>

"Cars should be more difficult to get."
"Speeds should be posted in the construction site so the driver knows how much to slow down."
"Stop using hand signals, motorists don't understand them."

13. <u>Are you proud of your profession?</u>

Ninety-one percent said "yes," 9 percent said "sort of, I guess."

14. <u>Do you ever get bored?</u>

Seventy-eight percent said "yes," 22 percent said "no."

A. <u>What do you do to keep your mind alert?</u>

"Talk to construction workers."
"Throw rocks."
"Sing."
"Keep mind occupied somehow."
"Do exercises."

15. <u>Do you feel that drivers fail to stop or slow down more under high traffic conditions, low traffic conditions, or is it just the personality of the driver?</u>

Ten percent said "High traffic conditions."
Thirty percent said "Low traffic conditions."
Sixty percent said "It is just the personality of the driver."

16. <u>How often do you get harassed by the drivers?</u>

Thirty percent said "Never."
Twenty percent said "Very seldom."
Ten percent said "Sometimes."
Forty percent said often.

A. Is the harassment sexual or is it because of delay?

Ninety-three percent said "Delay," 7 percent said "Sexual."

17. <u>Have you ever been harassed by the construction workers?</u>

Fifteen percent said "yes," 85 percent said "no."

A. If yes, what happened?

"One guy was just a jerk, nothing happened."
"One guy made me feel really uncomfortable, I confronted him and he stopped."
"One guy was a total creep, he got fired."

18. What type of job do you like the least for flagging?

Fifty percent said "Really slow, boring jobs."
Twenty percent said "Doesn't matter."
Five percent said "Cold and rainy."
Five percent said "Intersections."
Five percent said "Working for Ma Bell."
Five percent said "Manhole flagging."
Five percent said "Construction jobs."
Five percent said "Heavy traffic, downtown traffic."

19. What type of job do you like the most for flagging?

Fifty percent said "Nice, busy jobs."
Fifteen percent said "Utility company."
Fifteen percent said "Doesn't matter."
Five percent said "Medium traffic, one lane closed."
Five percent said "Heavy construction."
Five percent said "The one that pays the best."
Five percent said "Small country roads, residential."

20. Do you always wear an orange vest, work shoes, and a hard hat?

One hundred percent said "yes."

21. Are you responsible for seeing that the signing is properly located?

Twenty percent said "Yes," 40 percent said "No," and 40 percent said "Sometimes."

A. How often to you check the signs?

"Continuously (if you can see them)."
"At breaks (if you can't)."
"Usually get the crew to fix them."

22. What percentage of your assignments are a one-lane work zone?

Thirty percent said "less than 70 percent."
Thirty percent said "between 70 and 80 percent."
Five percent said "between 80 and 90 percent."
Thirty-five percent said "between 90 and 100 percent."

23. Have you ever used a walkie-talkie when flagging?

Eighty percent said "Yes," 20 percent said "No."

A. <u>If yes, under what conditions?</u>

"Can't see other flagger."
"Can hear logging trucks coming so you can prepare for them."
"Because we have to."

24. <u>Have you ever used a baton when flagging?</u>

Twenty percent said "Yes," 80 percent said "No."

A. <u>When did you use them?</u>

"For night flagging."

B. <u>How did they work?</u>

"Drivers took them."
"Didn't like it."
"Worked fine, people felt like part of the team."

25. <u>Have you ever worked with a pilot car when flagging?</u>

Fifteen percent said "Yes," 85 percent said "no."

A. <u>When did you use them?</u>

"When there was a long construction zone."

26. <u>Have you ever done night flagging?</u>

Seventy-five percent said "Yes," 25 percent said "No."

A. <u>How was it?</u>

"Didn't like it" (33 percent).
"Not quite as safe" (33 percent).
"It was fine" (33 percent).

APPENDIX C
RESULTS OF FIELD DATA COLLECTION QUEUE SIZE AND DELAY DATA

APPENDIX C
RESULTS OF FIELD DATA COLLECTION QUEUE SIZE AND DELAY DATA

TABLE C.1
QUEUE SIZE AND DELAY DATA FOR
EASTBOUND TRAFFIC THROUGH WORK ZONE
WITH FLAGGER ONLY CONTROL*

<u>Queue Size</u>	
Total no. of vehicles:	122
No. of vehicles in queue:	64
No. of queues:	28
Average queue sizes:	2.29
Total observation time:	2 hours (9:14 a.m. - 11:14 a.m., July 13, 1987)
Total no. of vehicles per hour:	61
Total no. of vehicles in queue per hour:	32
Total no. of queues/hour	14
Percentage of one vehicle queue:	67.9
Percentage of two vehicle queue:	14.3
Longest queue length:	9 vehicles
<u>Delay</u>	
No. of vehicles that experienced no stop delay:	58
Percentage of vehicles that experienced no stop delay:	47.5
Average stop delay for stopped vehicles only:	53.81 seconds
Average stop delay for all vehicles:	28.23 seconds

*Refer to Table 7-1 for field test conditions.

TABLE C.2
QUEUE SIZE AND DELAY DATA
FOR EASTBOUND TRAFFIC
FLAGGER AIDED WITH FLASHING RED LIGHT*

<u>Queue size</u>	
Total no. of vehicles:	174
No. of vehicles in queue:	59
No. of queues:	33
Average queue size:	1.79
Total observation time:	2 hours (11:34 a.m. - 1:34 p.m., July 14, 1987)
Total no. of vehicles per hour:	87
No. of vehicles in queue/hour:	30
No. of queues/hour:	17
Average queue size:	1.79
Percentage of one vehicle queues:	54.5
Percentage of two vehicle queues:	30.3
Largest queue length:	5
<u>Delay</u>	
No. of vehicles that experienced no stop delay:	115
Percentage of vehicles that experienced no stop delay:	89.1
Average stop delay for only stopped vehicles:	52.41 seconds
Average stop delay for all vehicles:	17.77 seconds

*Refer to Table 7-1 for field test conditions.

TABLE C.3

QUEUE SIZE AND DELAY DATA FOR WESTBOUND TRAFFIC THROUGH WORK ZONE FLAGGER ONLY CONTROL*

Queue size	
Total no. of vehicles:	107
No. of vehicles in queue:	49
No. of queues:	24
Average queue size:	2.04
Total observation time:	2 hours (9:14 a.m. - 11:14 a.m., July 13, 1987)
Total no. of vehicles per hour:	54
Total no. of vehicles in queue/hour:	25
Total no. of queues/hour:	12
Average queue size:	2.04
% of vehicles in 1-vehicle queue:	30.6
% of vehicles in 2-vehicle queue:	8.2
% of vehicles in 3-vehicle queue:	25.8
% of vehicles in 5-vehicle or less queue:	83.7
Longest queue length:	8
Delay	
No. of vehicles that experienced no stop delay:	58
Percentage of vehicles that experienced no stop delay:	54.2

*Refer to Table 7-1 for field test conditions.

TABLE C.3 (CONTINUED)

Average stop delay for stopped vehicles only:	46.89
Average stop delay for all vehicles only:	21.46

TABLE C.4
QUEUE SIZE AND DELAY DATA FOR
WESTBOUND TRAFFIC THROUGH WORK ZONE
FLAGGER AIDED WITH FLASHING RED LIGHT*

Queue size	
Total no. of vehicles:	147
No. of vehicles in queue:	60
No. of queues:	30
Average queue size:	2.00
Total observation time:	2 hours (11:34 a.m. - 1.:34 p.m., July 14, 1987)
Total no. of vehicles per hour:	74
Total no. of vehicles in queue/hour:	30
Total no. of queues/hour:	15
Average queue size:	2.00
% of 1-vehicle queue:	33.3
% of 2-vehicle queue:	33.3
% of 5-vehicle or less queue:	75
Longest queue length:	8
Delay	
No. of vehicles that experienced no stop delay:	87
Percentage of vehicles that experienced no stop delay:	59.2
Percentage of vehicles that experienced no stop delay:	66.53
Total stop delay per queue:	26.70

*Refer to Table 7-1 for field test conditions.

TABLE C.5
QUEUE SIZE AND DELAY DATA FOR EASTBOUND TRAFFIC THROUGH WORK ZONE
STOP SIGN CONTROL*

Queue size	
Total no. of vehicles:	33
No. of vehicles in queue:	31
No. of queues	17
Average queue sizes:	1.82
Total observation time:	20 min. (9:46 - 8:26 a.m., August 5, 1987)
Total no. of vehicles per hour:	99
Total no. of vehicles in queue per hour:	93
Total no. of queues/hour:	51
Percentage of one vehicle queue:	29.0
Percentage of two vehicle queue:	25.8
Longest queue length:	5 vehicles
Delay	
No. of vehicles that experienced no stop delay:	2
Percentage of vehicles that experienced no stop delay:	6.1
Percentage of vehicles that experienced no stop delay:	35.6
Total stop delay per queue:	30.2

*Refer to Table 7-1 for field test conditions.

TABLE C.6
QUEUE SIZE AND DELAY DATA FOR WESTBOUND TRAFFIC THROUGH WORK ZONE
STOP SIGN CONTROL*

Queue size	
Total no. of vehicles:	24
No. of vehicles in queue:	22
No. of queues	11
Average queue sizes:	2.0
Total observation time:	20 min. (7:46 - 8:26 a.m., August 5, 1987)
Total no. of vehicles per hour:	132
Total no. of vehicles in queue per hour:	66
Total no. of queues/hour:	33
Percentage of one vehicle queue:	31.8
Percentage of two vehicle queue:	0.0
Longest queue length:	5 vehicles
Delay	
No. of vehicles that experienced no stop delay:	2
Percentage of vehicles that experienced no stop delay:	8.3
Percentage of vehicles that experienced no stop delay:	8.3
Average stop delay for only stopped vehicles	192.6
Total stop delay per queue:	128.4

*Refer to Table 7-1 for field test conditions.

TABLE C.7
ARRIVAL TIMES AND STOP DELAY FOR EASTBOUND TRAFFIC THROUGH WORK ZONE
(SR 970, TEANAWAY RIVER TO SR 97 PROJECT)
WHEN CONTROLLED WITH FLAGGER ONLY (7-14-87)*

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
9:15:00	30
15:30	43
15:45	28
15:50	23
15:55	18
17:56	0
17:58	0
18:00	0
22:03	26
22:03	26
22:44	0
22:44	0
23:35 (4 vehicles)	0
25:29	61
27:35	55
27:27	57
28:05	0
28:49	0
31:21	0
33:30	0
33:35	0
34:12	0
9:34:12	0
37:50	20
37:51	19
38:10	0
38:30	0
39:49	36
39:49	36
39:50	36
39:51	36
42:00	24
42:00	24
44:50	0
45:10	0 (Didn't stop as required)

*Refer to Table 7-1 for field test conditions.

TABLE C-7 (CONTINUED)

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
46:10	36
51:46	37
(9 vehicles)	
56:39	0
57:08	0
59:10	50
59:10	82
10:01:50	0
02:30	0
10:02:30	0
03:30	37
04:50	0
04:59	0
05:36	64
05:36	64
07:20	40
08:40	0
(2 vehicles)	
09:18	0
09:20	0
09:50	20
11:14	53
12:27	0
12:40	0
14:50	34
14:50	34
14:55	125
(3 vehicles)	
17:20	0
18:30	0
19:26	4
20:00	80
20:02	80
22:30	30
23:50	35
23:50	35
23:50	35
10:23:50	35
25:00	0
25:00	0
26:26	0
27:50	60
27:50	60
29:00	82
29:00	82

TABLE C.7 (CONTINUED)

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
10:29:00	82
35:39	18
35:39	18
35:39	18
36:36	0
37:05	75
37:05	75

TABLE C.8
ARRIVAL TIMES AND STOP DELAY FOR WESTBOUND TRAFFIC
THROUGH WORK ZONE (SR 970, TEANAWAY RIVER TO SR 97 PROJECT)
WHEN CONTROLLED WITH FLAGGER ONLY (7-14-87)*

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
9:15:00	30
17:05	0
19:10	10
19:15	5
19:35	0
20:00	0
20:20	0
20:35	0
20:45	0
20:53	0
21:55	0
23:55	45
23:55	45
25:29	0
26:01	0
26:03	0
27:00	0
30:34	0
30:40	0
30:49	0
31:40	26
31:50	16
33:55	45
35:10	0
36:40	0
37:20	0
38:50	38
38:51	38
38:52	38
41:30	0
42:03	0
43:20	20
43:20	20
43:20	20
44:00	0
45:10	35
46:40	0
48:00	0
49:55	0
51:09	0

*Refer to Table 7-1 for field test conditions.

TABLE C.8 (CONTINUED)

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
9:51:46	96
51:47	96
51:48	96
51:49	96
51:50	96
51:51	96
54:50	0
54:50	0
56:07	0
57:56	0
58:08	0
59:09	0
59:09	0
59:09	0
59:09	0
59:09	0
10:00:52	9
03:30	0
04:07	0
04:07	0
04:07	0
04:07	0
04:07	0
06:40	40
09:30	20
09:40	20
10:10	51
11:22	0
11:30	0
12:04	56
13:47	11
14:50	34
14:50	34
14:55	65
15:00	0
16:21	0
21:02	0
21:50	25
22:10	0
22:30	0
22:37	0
23:00	50
25:00	30
25:00	30
25:00	30

TABLE C.8 (CONTINUED)

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
10:26:26	56
27:50	0
27:52	0
28:30	0
28:30	0
28:50	40
29:00	41
29:20	42
29:50	0
31:20	0
33:33	0
33:34	0
34:15	0
34:15	0
34:59	0
35:08	0
35:12	0
35:13	0
35:57	78
35:57	78
35:57	78
35:57	78
35:57	78
37:38	0
39:45	0
39:45	0
41:25	0
42:50	0
43:10	0
44:41	0
45:37	0
47:15	0
47:50	80
(5 vehicles)	
48:50	60
50:40	0
(2 vehicles)	
51:50	10
(2 vehicles)	
52:10	0
51:50	140
54:10	5
54:40	0
54:50	0
55:10	50

TABLE C.8 (CONTINUED)

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
11:56:50	50
58:10	0
59:10	32
12:02:10 (2 vehicles)	0
03:20	0
03:36	0
04:10	40
04:40	0
05:40 (2 vehicles)	40
07:30	20
07:35	0
08:40	0

TABLE C.9
ARRIVAL TIMES AND STOP DELAY FOR
EASTBOUND TRAFFIC THROUGH WORK ZONE (SR 970, TEANAWAY RIVER TO SR 97 PROJECT) WHEN CONTROLLED BY FLAGGER AIDED WITH FLASHING RED LIGHT (7-15-87)*

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
11:35:09 (2 vehicles)	11
36:03	0
37:00 (2 vehicles)	48
37:50	0
37:58	0
38:30	0
38:50	0
38:58	0
39:50 (2 vehicles)	25
40:40	0
41:13	0
41:55	0
41:56 (2 vehicles)	115
43:00	0
43:10	0
44:20	0
46:00	0
46:15	0
46:50	0
12:09:00	0
09:05	0
09:10	0
09:20	0
09:30	0
10:10	0
10:50	80
13:00	0
13:57	103
13:59 (3 vehicles)	91
16:34 (4 vehicles)	46
18:00	46
19:30	0

*Refer to Table 7-1 for field test conditions.

TABLE C.9 (CONTINUED)

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
12:19:35 (3 vehicles)	0
20:30 (3 vehicles)	0
21:30	0
22:30	0
22:41	0
24:23 (3 vehicles)	0
26:08	0
26:08	0
26:30	0
26:30	0
27:22	0
28:00 (5 vehicles)	50
29:48	60
31:39	0
32:00	62
33:10	0
33:20	0
33:30	0
33:20	71
34:09	0
34:20	0
35:10	0
35:20	0
35:40	0
36:20	0
37:10	55
39:20	20
40:20	0
40:20	0
40:20	0
40:20	0
37:00 (2 vehicles)	48
37:50	0
37:58	0
38:30	0
38:50	0
38:58	0
39:50 (2 vehicles)	25
40:40	0

TABLE C.9 (CONTINUED)

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
12:41:13	0
41:55	0
41:56 (2 vehicles)	115
43:00	0
43:10	0
44:20	0
46:00	0
46:15	0
46:50	0
27:22	0
28:00 (5 vehicles)	50
29:48	60
31:39	0
32:00	62
33:10	0
33:20	0
33:30	0
33:20	71
34:09	0
34:20	0
35:10	0
35:20	0
35:40	0
36:20	0
37:10	55
39:20	20
40:20	0
40:20	0
40:20	0
40:20	0
40:20	0
41:25	0
41:50	0
41:50	0
42:40	0
44:20	27
44:58	0
46:55	0
47:26	0
49:50	0
51:14	0
52:00	0
52:50	0

TABLE C.9 (CONTINUED)

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
12:53:09	0
53:09	0
54:50	49
56:30	0
57:06	0
58:50	0
59:30	83
59:30	83
1:01:16	0
01:18	0
02:14	0
06:12	0
(5 vehicles)	
08:06	0
08:13	0
08:30	0
08:35	0
09:48	0
(3 vehicles - 3 sec. intervals)	
10:10	0
10:55	0
11:50	10
12:30	50
12:35	50
16:04	0
16:10	0
(4 vehicles)	
18:00	15
19:00	0
19:20	0
19:25	0
(2 vehicles)	
22:28	0
22:50	0
(4 vehicles)	
23:30	0
(2 vehicles)	
24:56	24
25:50	0
26:20	40
27:10	0
29:28	52
31:50	0
33:20	50
(2 vehicles)	
34:50	0

TABLE C.10
ARRIVAL TIMES AND STOP FOR
WESTBOUND TRAFFIC THROUGH WORK ZONE (SR 970, TEANAWAY RIVER TO SR 97 PROJECT) WHEN CONTROLLED WITH FLAGGER AIDED WITH FLASHING RED LIGHT (7-15-87)*

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
11:34:40	0
35:20 (2 vehicles)	54
36:30	0
37:10	0
39:05	3
39:07	0
39:50	0
39:52	0
39:54	0
39:57	0
41:50	0
41:53	0
42:00	0
42:05	0
42:06	144
42:50	92
44:50	0
46:10	110
46:20	110
47:50 (3 vehicles)	5
48:40	0
48:50	0
50:10 (7 vehicles)	63
51:50	54
52:50	0
53:20	0
53:40	0
53:45	0
54:10	60
55:10	0
56:20	19
57:10 (2 vehicles)	0
58:50	0
12:00:40	0

*Refer to Table 7-1 for field test conditions.

TABLE C.10 (CONTINUED)

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
12:01:30	0
01:40	0
01:46	0
01:50	0
01:59	0
02:10	0
12:03:36 (2 vehicles)	44
04:50	50
06:09	48
10:50 (3 vehicles)	0
14:40	0
15:00 (3 vehicles)	94
17:20 (2 vehicles)	56
18:50	71
23:10 (2 vehicles)	20
23:50	0
24:50	0
28:00	0
28:40 (8 vehicles)	68
30:50 (3 vehicles)	70
33:20	71
34:50	0
35:40 (4 vehicles)	92
38:20	0
39:01	0
39:10	0
39:20	0
42:09 (2 vehicles)	27
43:48	0
44:25	0
45:28	0
45:50 (4 vehicles)	0
48:33 (8 vehicles)	0
50:00 (3 vehicles)	0

TABLE C.10 (CONTINUED)

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
12:54:05	0
57:06	14
57:57	0
58:10	0
59:30	0
59:44	0
59:50	0
02:14	0
03:19	0
03:24	0
03:36	0
04:10	0
04:14	0
04:59	0
05:06	0
05:10	0
05:20	0
05:25	0
05:30	0
06:12	43
07:05	0
07:14	0
07:22	0
10:50	40
12:20	13
12:34	0
14:10	15
17:10	0
17:20	0
19:20	0
19:51	0
19:56	0
20:50	0
22:20 (2 vehicles)	110
23:30	62
24:50 (2 vehicles)	90
28:00	0
29:28 (2 vehicles)	0
31:50	22
33:20	0
34:00 (4 vehicles)	75

TABLE C.11
ARRIVAL TIMES AND STOP DELAY FOR EASTBOUND TRAFFIC THROUGH CONSTRUCTION ZONE (SR 970, TEANAWAY RIVER TO SR 97 PROJECT) WHEN CONTROLLED BY STOP SIGN*

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
7:46:00 (5 vehicles)	41
7:47:00	60
7:49:00	20
7:49:40	13
7:53:14	13
7:53:36	4
55:01	3
55:30	5
55:35 (2 vehicles)	95
8:00:15	55
00:40	0
01:20 (2 vehicles)	40
02:40 (3 vehicles)	20
05:10 (2 vehicles)	10
07:30	10
08:08 (3 vehicles)	0
16:20	15
18:15 (3 vehicles)	15
8:18:59	60
20:26 (5 vehicles)	0
21:00	0
23:30	0
23:45	98

*Refer to Table 7-1 for field test conditions.

TABLE C.12
ARRIVAL TIMES AND STOP DELAY FOR WESTBOUND TRAFFIC THROUGH CONSTRUCTION ZONE (SR 970, TEANAWAY RIVER TO SR 97 PROJECT) WHEN CONTROLLED BY STOP SIGN*

Vehicle Arrival Time	Vehicle Stop Delay (sec.)
8:09:21 (6 vehicles)	0
11:25 (6 vehicles)	0
14:50	0
16:22	0
17:20	0
17:40	0
18:40	230 (erratic driving)
18:45 (5 vehicles)	239
23:40 (3 vehicles)	40
25:25	35
26:14	0

*Refer to Table 7-1 for field test conditions.

APPENDIX D
RESULTS OF FIELD DATA COLLECTION - SPEED DATA

APPENDIX D
RESULTS OF FIELD DATA COLLECTION - SPEED DATA*

TABLE D.1
EASTBOUND APPROACH SPEED DATA

	Before Construction	Flagger Only Control	Flagger Control Aided with "Flashing Red" Light
Average speed	57.4	55.7	55.0
Median speed	57.6	56.6	56.3
85th percentile speed	63.1	61.7	62.0
% Exceeding 45	98.5	95.2	93.4
% Exceeding 55	67.6	55.5	52.9
% Exceeding 60	23.8	17.1	18.0
% Exceeding 65	6.7	4.9	5.7
% Exceeding 70	1.1	0.9	0.9
% Exceeding 75	0	0	0
Sample size	1237	1192	1309

*Refer to Table 7-1 for field test conditions.

TABLE D.2
WESTBOUND APPROACH SPEED DATA*

	Before Construction	Flagger Only Control	Flagger Control Aided with "Flashing Red" Light
Average speed	57.6	44.4	44.0
Median speed	58.3	44.8	44.8
85%tile speed	64.8	53.7	52.8
% Exceeding 45	91.8	48.9	48.6
% Exceeding 55	68.9	8.9	7.2
% Exceeding 60	36.3	3.0	1.4
% Exceeding 65	13.7	1.0	0.0
% Exceeding 70	3.7	0.3	0.0
% Exceeding 75	0.0	0.0	0.0
Sample size	1210	630	782

*Refer to Table 7-1 for field test conditions.

TABLE D.3
SPEED THROUGH THE CONSTRUCTION ZONE
(BOTH DIRECTIONS OF TRAFFIC)*

	Flagger Control Only	Flagger Control plus Flashing Red
Average speed	28.6	27.6
Median speed	28.5	27.7
85th percentile speed	34.6	33.7
% Exceeding 45	0.7	0.3
% Exceeding 55	0.2	0.0
% Exceeding 60	0.1	0.0
% Exceeding 65	0.1	0.0
% Exceeding 70	0.1	0.0
% Exceeding 75	0.0	0.0
Sample size	1892	2406

*Refer to Table 7-1 for field test conditions.

Table D.4 Approach Speeds before Start of Construction*

Time	Average Eastbound Vehicular Approach Speed	n	Average Westbound Vehicular Approach Speed	n	Average Vehicular Speed Through Construction Zone (both directions)
12 a.m.	58.3	20	59.3	8	58.6
1 a.m.	58.5	10	58.0	7	58.3
2 a.m.	55.9	7	58.0	4	56.7
3 a.m.	56.1	8	62.4	9	59.4
4 a.m.	56.7	15	66.5	13	61.3
5 a.m.	59.8	11	62.4	9	61.0
6 a.m.	56.0	20	62.1	40	60.1
7 a.m.	55.3	52	54.5	43	54.9
8 a.m.	58.5	72	49.5	77	53.9
9 a.m.	56.0	88	47.1	75	51.9
10 a.m.	57.0	72	49.7	84	53.1
11 a.m.	58.2	109	61.9	71	59.7
12 p.m.	56.9	80	58.8	74	57.8
1 p.m.	57.7	90	58.2	86	57.9
2 p.m.	57.2	91	57.2	103	57.2
3 p.m.	56.7	91	58.5	99	57.6
4 p.m.	58.2	89	60.0	99	59.2
5 p.m.	58.7	62	59.8	85	59.3
6 p.m.	58.2	80	62.4	71	60.2
7 p.m.	56.2	46	63.2	53	60.0
8 p.m.	58.4	47	61.9	40	60.0
9 p.m.	59.0	36	59.9	21	59.3
10 p.m.	56.2	22	60.7	22	58.5
11 p.m.	57.5	19	59.3	15	58.3
mean	57.4		57.6		57.5
std. dev.	1.195		4.589		2.446

* The speed data were collected on Tuesday, July 7, 1987 (Temperature = 50-90°F, clear skies), a week before the start of construction at the site

Table D.5 Traffic Speeds Through Construciton Zone During Construction (Flagger only control)

Time	Average Eastbound Vehicular Approach Speed	n	Average Westbound Vehicular Approach Speed	n	Average Vehicular Speed Through Construction Zone (both directions)	
12 a.m.	54.2	13	49.0	10	–	–
1 a.m.	53.5	11	50.9	7	–	–
2 a.m.	53.0	8	48.6	8	–	–
3 a.m.	53.7	14	48.0	6	–	–
4 a.m.	57.5	11	55.5	12	–	–
5 a.m.	50.9	21	48.0	16	–	–
6 a.m.	56.3	32	47.0	43	–	–
7 a.m.	56.0	32	48.2	33	–	–
8 a.m.	56.0	58	47.8	62	–	–
9 a.m.	56.3	63	46.2	74	28.2	142
10 a.m.	54.2	93	41.2	77	24.8	143
11 a.m.	56.7	90	36.8	70	24.0	186
12 p.m.	54.9	78	43.5	79	28.8	154
1 p.m.	56.1	76	43.5	76	29.4	155
2 p.m.	55.6	81	44.2	57	29.4	149
3 p.m.	57.5	88	45.7	93	30.2	173
4 p.m.	56.5	81	44.7	96	28.5	168
5 p.m.	56.8	83	47.1	84	30.4	152
6 p.m.	57.3	72	47.6	60	31.2	133
7 p.m.	57.1	53	46.9	55	29.5	104
8 p.m.	56.6	56	44.1	54	30.2	86
9 p.m.	51.9	38	48.0	41	29.2	71
10 p.m.	50.9	24	51.2	17	30.4	43
11 p.m.	52.4	16	46.2	22	29.8	33
mean	57.4	1192	45.25	1152	28.6	1892
std. dev.	2.065		3.618		2.007	

-- No data available

Table D.6 Approach Speeds Through Construction Zone During Construction (Flagger Aided with Flashing Red Light)

Time	Average Eastbound Vehicular Approach Speed	n	Average Westbound Vehicular Approach Speed	n	Average Vehicular Speed Through Construction Zone (both directions)	
12 a.m.	51.1	16	42.3	7	29.6	25
1 a.m.	51.1	8	48.0	2	28.9	11
2 a.m.	48.8	6	43.0	8	27.6	12
3 a.m.	49.1	18	52.6	12	29.9	24
4 a.m.	47.4	26	51.0	10	31.1	32
5 a.m.	54.1	19	51.6	21	27.8	39
6 a.m.	55.0	32	44.4	32	24.4	61
7 a.m.	54.7	42	47.5	42	26.8	77
8 a.m.	57.8	52	44.0	60	28.0	95
9 a.m.	56.5	63	44.7	84	26.7	144
10 a.m.	55.4	98	39.9	105	27.3	182
11 a.m.	57.5	87	43.0	102	25.8	178
12 p.m.	53.6	100	44.3	74	26.5	165
1 p.m.	55.2	88	42.2	77	25.8	149
2 p.m.	57.0	109	45.6	96	26.3	211
3 p.m.	57.7	93	44.7	103	26.3	201
4 p.m.	56.5	85	48.0	94	28.6	171
5 p.m.	55.8	75	47.7	64	29.6	142
6 p.m.	54.6	85	46.7	63	29.2	145
7 p.m.	57.3	60	47.9	49	29.9	106
8 p.m.	55.4	57	46.5	50	29.7	102
9 p.m.	50.8	32	47.8	28	29.4	58
10 p.m.	46.5	36	42.4	16	28.8	49
11 p.m.	46.4	22	46.5	10	30.8	27
mean	55.0	1309	45.1	1212	27.6	2406
std. dev.	3.69		3.163		1.770	

APPENDIX E
STATISTICAL SIGNIFICANCE TESTS

SIGNIFICANCE TESTS

Two-sided hypothesis tests were conducted on the speed, queue size and stop delay data. The decision rule was set up in the standard normal distribution (z). The sample mean $\bar{x}$ is converted to a z value by using the standarization formula:

$$z = \frac{\bar{x} - \mu}{\sigma/\sqrt{n}}$$

There is significant difference between two data samples existing at the 95 percent confidence level if $z < -z_{0.025}$ or $z > z_{0.025}$ ($z_{0.025} = 1.96$).

SPEEDS

Mean Eastbound Approach Traffic Speeds when Work Zone was Controlled By:

Flagger Only	57.4
Flagger Aided with Flashing Red Light	55.0

Standard Deviation of Eastbound Approach Traffic Speeds when Work Zone was Controlled By:

Flagger Only	3.69 (n = 1192)
Flagger Aided with Flashing Red Light	2.065 (n = 1309)

Westbound Approach Traffic Speeds when Work Zone was Controlled By:

Flagger Only	45.25
Flagger Aided with Flashing Red Light	45.10

Standard Deviation of Westbound Approach Traffic Speeds when Work Zone was Controlled by:

Flagger Only	3.62 (n = 1152)
Flagger Aided with Flashing Red Light	3.16 (n = 1212)

Through Traffic Speeds when Work Zone was Controlled By:

Flagger Only	28.6
Flagger Aided with Flashing Red Light	27.6

Standard Deviation of Through Traffic Speeds when Work Zone was Controlled By:

Flagger Only	2.01 (n = 1892)
Flagger Aided with Flashing Red Light	1.77 (n = 2406)

Difference in Eastbound Approach Speed When Zone is Controlled Alternately By Flagger and Flagger Aided with Flashing Red Light Control

$$z = \frac{\bar{x}_F - \bar{x}_R}{\sqrt{\frac{\sigma_F^2}{n_F} + \frac{\sigma_R^2}{n_R}}} = \frac{57.4 - 55}{\sqrt{\frac{3.69}{1192} + \frac{2.065}{1309}}} = \frac{2.5}{\sqrt{0.0036731}} = \frac{2.4}{0.068} = 35.11 > 1.96$$

∴ significance at 95 percent level

Difference Westbound Approach Speed When Zone is Controlled Alternately By Flagger and Flagger Aided with Flashing Red Light Control

$$z = \frac{45.25 - 45.1}{\sqrt{\frac{3.618}{1152} + \frac{3.163}{1212}}} = \frac{0.15}{0.023041} = 1.978 > 1.96$$

∴ significance at 95 percent level

Speeds Through Construction Zone (Both Directions)

$$z = \frac{28.6 - 27.6}{\sqrt{\frac{2.007}{1892} + \frac{1.770}{2406}}} = \frac{1}{0.0423844} = 23.594 > 1.96$$

∴ significance at 95 percent level

AVERAGE QUEUE SIZE

Mean Queue Size:	EB	WB
For Flagger Only Controlled Work Zone, $\bar{x}_F$ =	1.86 (n = 28)	2.04 (n = 30)
For Flagger Aided with Flashing Red Light Controlled Work Zone, x_{RZ} =	1.79 (n = 33)	1.97 (n = 24)
For Stop Sign Controlled Work Zone, $\bar{x}_s$ =	1.82 (n = 17)	2.00 (n = 11)
Standard Deviation of Queue Size:		
For Flagger Only Controlled Work Zone, σ_F^2	1.78	1.78
For Flagger Aided with Flashing Red Light Controlled Work Zone, σ_R^2	1.19	1.71
For Stop Sign Controlled Work Zone, σ_S^2	1.13	1.48

Difference in Queue Size Between Flagger Only Controlled Work Zone and Flagger Aided with Flashing Red Light Controlled Work Zone

Eastbound

$$z = \frac{\bar{x}_F - \bar{x}_R}{\sqrt{\frac{\sigma_F^2}{n_F} + \frac{\sigma_R^2}{n_R}}} = \frac{1.86 - 1.79}{\sqrt{\frac{1.78}{28} + \frac{1.19}{33}}} = 0.22 < 1.96$$

Difference is not significant at 95 percent confidence level.

Westbound

$$z = \frac{2.04 - 1.97}{\sqrt{\frac{1.78}{30} + \frac{1.71}{24}}} = 0.19 < 1.96$$

Difference is not significant at 95 percent confidence level.

Difference in Queue Size Between Flagger Only Control and Stop Sign Control

Eastbound

$$z = \frac{\bar{x}_F - \bar{x}_S}{\sqrt{\frac{\sigma_F^2}{n_F} + \frac{\sigma_S^2}{n_S}}} = \frac{1.86 - 1.82}{\sqrt{\frac{1.78}{28} + \frac{1.13}{17}}} = 0.05 < 1.96$$

Difference is not signifcant at 95 percent confidence level.

Westbound

$$z = \frac{2.04 - 2.00}{\sqrt{\frac{1.78}{30} + \frac{1.48}{11}}} = 0.09 < 1.96$$

Difference is not signifcant at 95 percent confidence level.

Difference in Queue Size Between Flagger Aided with Flashing Red Light Control and Stop Sign Control

Eastbound

$$z = \frac{\bar{x}_F - \bar{x}_S}{\sqrt{\frac{\sigma_F^2}{n_F} + \frac{\sigma_S^2}{n_S}}} = \frac{1.79 - 1.82}{\sqrt{\frac{1.19}{33} + \frac{1.13}{17}}} = 0.09 < 1.96$$

Difference is not signifcant at 95 percent confidence level.

Westbound

$$z = \frac{\bar{x}_R - \bar{x}_S}{\sqrt{\frac{\sigma_R^2}{n_R} + \frac{\sigma_S^2}{n_S}}} = \frac{1.97 - 2.00}{\sqrt{\frac{1.71}{24} + \frac{1.48}{11}}} = 0.07 < 1.96$$

Difference is not signifcant at 95 percent confidence level.

AVERAGE STOP DELAY

Average Stop Delay:	EB	WB
For Flagger Only Controlled Work Zone, $\overline{X}_F$	28.23 (n = 122)	21.46 (n = 107)
For Flagger Aided with Flashing Red Light Controlled Work Zone, X_R	17.77 (n = 174)	27.21 (n = 147)
For Stop Sign Controlled Work Zone, $\overline{X}_S$	31.39 (n = 33)	107.75 (n = 24)

Standard Deviation of Average Stop Delay:	EB	WB
For Flagger Only Controlled Work Zone, σ_F^2	34.17	30.34
For Flagger Aided with Flashing Red Light Controlled Work Zone, σ_R^2	30.21	43.05
For Stop Sign Controlled Work Zone, σ_S^2	31.52	104.51

Difference in Average Stop Delay Between Flagger Only Controlled Work Zone and Flagger Aided with Flashing Red Light Controlled Work Zone

Eastbound

$$z = \frac{\bar{x}_F - \bar{x}_R}{\sqrt{\frac{\sigma_F^2}{n_F} + \frac{\sigma_R^2}{n_R}}} = \frac{28.33 - 17.77}{\sqrt{\frac{34.17}{122} + \frac{30.21}{174}}} = 15.52 > 1.96$$

Difference is significant at 95 percent confidence level.

Westbound

$$z = \frac{\bar{x}_F - \bar{x}_R}{\sqrt{\frac{\sigma_F^2}{n_F} + \frac{\sigma_R^2}{n_R}}} = \frac{21.46 - 27.21}{\sqrt{\frac{30.34}{107} + \frac{43.05}{147}}} = -7.57 < -1.96$$

Difference is significant at 95 percent confidence level.

Difference in Average Stop Delay Between Flagger Only Controlled Work Zone and Stop Sign Controlled Work Zone

Eastbound

$$z = \frac{\bar{x}_F - \bar{x}_S}{\sqrt{\frac{\sigma_F^2}{n_F} + \frac{\sigma_S^2}{n_S}}} = \frac{29.23 - 31.39}{\sqrt{\frac{34.17}{122} + \frac{31.52}{33}}} = -2.84 < -1.96$$

Difference is significant at the 95 percent confidence level.

Westbound

$$z = \frac{\bar{x}_F - \bar{x}_S}{\sqrt{\frac{\sigma_F^2}{n_F} + \frac{\sigma_S^2}{n_S}}} = \frac{21.46 - 107.75}{\sqrt{\frac{30.34}{107} + \frac{104.51}{24}}} = -40.07 > -1.96$$

Difference is significant at the 95 percent confidence level.

Difference in Average Stop Delay Between Flagger Aided with Flashing Red Light Controlled Work Zone and Stop Sign Controlled Work Zone

Eastbound

$$z = \frac{\bar{x}_R - \bar{x}_S}{\sqrt{\frac{\sigma_F^2}{n_F} + \frac{\sigma_S^2}{n_S}}} = \frac{17.77 - 31.39}{\sqrt{\frac{34.17}{122} + \frac{31.52}{33}}} = -12.25 < -1.96$$

Difference is significant at the 95 percent confidence level.

Westbound

$$z = \frac{\bar{x}_R - \bar{x}_S}{\sqrt{\frac{\sigma_F^2}{n_F} + \frac{\sigma_S^2}{n_S}}} = \frac{27.21 - 107.75}{\sqrt{\frac{43.05}{147} + \frac{104.51}{24}}} = -37.36 < -1.96$$

Difference is significant at the 95 percent confidence level.

APPENDIX F
FIELD DATA COLLECTION AT SR 2 BRIDGE RAIL TREATMENT PROJECT

FIELD DATA COLLECTION AT SR 2 BRIDGE RAIL TREATMENT PROJECT

The construction project was located in the vicinity of milepost 33 on State Route (SR) 2. The westbound approach to the site of the construction projects consists of a 955 foot radius curve whose point of curvature (PC) is at the west end of the work zone. The eastbound approach to the site is 1,000 feet of tangent section. The pre-construction speed limit for the route is 55 mph.

The purpose of the data collection effort at this SR 2 site was to evaluate at least two flagging techniques (flagger only and temporary traffic signal). However, due to a last minute refusal by the contractor to allow further testing, only data on flagger control was obtained at this site.

Table F.1 contains the summary of the data obtained from the SR 2 site. Details of the data are contained in Tables F.2 and F.3. Since no comparative data were obtained, this information was not used to make any judgements or assessments of flagging effectiveness.

Westbound

955 foot Radius Curve whose Point of Curvature is at the end of the construction zone.

Eastbound

Target section for a 1000 foot

TABLE F.1
FIELD DATA COLLECTED AT SR 2 BRIDGE RAIL TREATMENT PROJECT

	Eastbound*	Westbound*
Mean Approach Vehicular Speed (mph)	39.43 (s = 7.25)	42.72 (s = 5.74)
Mean through Zone Speed (mph)	23.67 (s = 28.07)	22.41 (s = 3.69)
Mean Queue Size	2.50 (s = 1.24)	2.56 (s = 2.00)
Mean Stop Delay (sec)	8.62 (s = 13.19) (for all vehicles) 24.38 (for stopped + vehicles only)	25.37 (s = 27.03) (for all vehicles) 27.02 (for stopped vehicles only)
Vehicular Volume	82	54
Date of Field Tests	April 24, 1987 Friday (cloudy and warm)	April 24, 1987 Friday (cloudy and warm)

*where s = standard deviation of the sample data

APPENDIX G
SPEED AND ARRIVAL TIMES FOR TRAFFIC PROCEEDING THROUGH WORK ZONE (SR 2 BRIDGE RAIL PROJECT)

TABLE G.1
SPEEDS AND ARRIVAL TIMES FOR EASTBOUND TRAFFIC THROUGH WORK ZONE (SR 2 BRIDGE RAIL PROJECT)

Vehicle Arrival Time	Vehicle Stop Delay (sec)	Approach Speed (mph)	Through Speed (mph)
9:37:30	0	39	15
9:37:32	0	39	15
9:37:35	0	39	15
9:37:42	0	93	15
9:39:47	0	41	21
40:07	13	37	0
40:30	0	48	13
40:42	0	41	14
43:34	6	44	0
44:14	20	44	0
45:14	20	44	0
45:15	12	40	0
45:30	13	29	15
48:24	18	36	0
50:11	0	47	15
50:37	0	48	15
51:33	4	43	0
51:52	0	50	28
52:27	0	44	20
52:44	0	41	18
53:37	0	49	25
53:39	0	49	24
53:42	0	49	21
53:48	0	44	16
53:53	0	46	22
54:01	0	45	25
56:05	12	51	10
56:30	0	41	9
56:39	0	46	25
56:45	0	41	25
57:10	41	37	10
57:21	31	37	10
58:57	0	52	21
59:02	0	40	25
10:01:05	32	34	10
01:41	0	40	5
04:20	0	41	17
04:54	14	38	10
04:57	13	38	10
05:00	16	38	10
05:00	16	38	10
05:00	16	38	10
05:00	16	38	10

TABLE G.2
SPEEDS AND ARRIVAL TIMES FOR EASTBOUND TRAFFIC THROUGH WORK ZONE (SR 2 BRIDGE RAIL PROJECT)

Vehicle Arrival Time	Vehicle Stop Delay (sec)	Approach Speed (mph)	Through Speed (mph)
9:41:00	0	35	25
9:41:55	35	40	29
9:43:50	15	41	16
9:43:50	15	41	16
9:43:50	15	41	16
9:43:50	15	41	16
45:20	0	42	25
45:55	25	33	11
45:55	25	33	11
47:53	0	42	24
48:10	0	48	24
48:55	35	29	17
48:55	35	29	17
48:55	35	29	17
48:55	35	29	17
48:55	35	29	17
50:05	0	38	23
50:05	0	38	23
50:05	0	38	23
51:28	0	46	25
54:23	0	34	18
54:23	34	35	23
55:40	0	23	18
(9 vehicles)			
56:10	0	33	21
(6 vehicles)			
57:10	10	51	25
58:25	25	51	29
58:25	25	51	29
58:25	25	51	29
58:25	25	51	29
59:10	0	41	21
10:00:55	20	39	17
00:55	20	39	17
00:55	20	39	17
01:40	0	43	29
02:05	15	43	22
02:05	15	43	22
03:35	40	33	19
03:35	40	33	19
04:58	0	43	24
04:58	0	43	24
05:04	11	36	19

TABLE G.2 (CONTINUED)

Vehicle Arrival Time	Vehicle Stop Delay (sec)	Approach Speed (mph)	Through Speed (mph)
10:05:04	11	36	19
05:04	11	36	19
05:04	11	36	19
06:58	0	47	18
06:58	0	47	18
07:50	0	51	17
07:50	0	43	22
07:55	0	43	22
08:15	0	41	21
08:15	0	41	21
09:35	0	48	20
10:10	0	44	28
11:40	30	38	18
11:40	30	38	18
12:50	0	43	17
13:10	0	41	27
13:10	0	41	27
13:10	0	41	27
13:10	0	41	27
13:10	0	41	27
14:55	0	39	21
14:55	0	39	21
15:10	0	48	18
15:35	29	43	16
15:35	29	43	16

TABLE G.3
SPEEDS AND ARRIVAL TIMES FOR WESTBOUND TRAFFIC THROUGH WORK ZONE (SR 2 BRIDGE RAIL PROJECT)

Vehicle Arrival Time	Vehicle Stop Delay (sec)	Approach Speed (mph)	Through Speed (mph)
10:23:30	25	40	26
24:35	15	46	26
24:35	15	46	26
25:10	0	48	24
25:10	0	48	24
26:30	0	44	33
27:20	10	48	21
27:20	10	48	21
29:20	0	55	31
31:45	45	45	27
32:55	0	34	22
33:45	10	35	22
33:45	10	35	22
33:45	10	35	22
33:45	10	35	22
35:55	55	45	24
36:10	0	45	24
36:10	0	45	24
36:10	0	45	24
36:50	60	45	24
36:50	60	45	24
38:05	10	50	22
38:05	10	50	22
40:00	15	34	27
40:35	35	35	27
40:35	35	35	27
42:50	55	46	17
42:50	55	46	24
42:50	55	37	24
42:50	55	37	24
44:50	15	43	24
46:10	20	50	31
47:20	20	48	20
(6 vehicles)			
48:30	29	44	23
49:25	50	40	20
49:25	50	40	20
52:20	50	37	26
53:20	50	35	18
(7 vehicles)			