FINAL REPORT

EFFECTIVENESS OF CHANGEABLE MESSAGE SIGNS IN CONTROLLING VEHICLE SPEEDS IN WORK ZONES

NICHOLAS J. GARBER, Ph.D.
Professor, Civil Engineering Department,
University of Virginia
Faculty Research Engineer

SURBHI T. PATEL, E.I.T.
Graduate Research Assistant

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16. Abstract

This study evaluated the effectiveness of the CMS with radar unit in reducing work zone speeds. Four CMS messages designed to warn drivers that their speed exceeded the maximum safe speed were tested at seven work zones on two interstate highways in Virginia. Speed and volume data for the whole population traveling through the work zone were collected with automatic traffic counters. To assess the effect of CMS on high-speed drivers in particular, vehicles that triggered the radar-activated display were videotaped as they passed through the work zone.Using the data obtained from the traffic counters and videotapes, speed characteristics were determined at the beginning, middle, and end of the work zone. Those characteristics were computed for the whole population and for high-speed vehicles separately. Statistical tests were then conducted using these speed characteristics to determine whether significant reductions in speed accompanied the use of CMS. Odds ratios were first calculated to compare the odds for speeding when using CMS with the odds for speeding when using the Manual on Uniform Traffic Control Devices (MUTCD) signing only. These odds ratios indicated that CMS effectively reduced the number of vehicles speeding by any amount, by 5 mph or more, and by 10 mph or more in the work zone. When analysis of variance was used to compare speeds when using the CMS with speeds when using MUTCD signing only, all of the speed characteristics--average speeds, 85th percentile speeds, speed variance, and the percentage of vehicles speeding by any amount, by 5 mph or more, and by 10 mph or more-- were reduced with any of the four CMS messages. In some cases, these reductions were not significant at $\alpha = 0.05$. The messages were rated according to their level of effectiveness in the following order: [1] YOU ARE SPEEDING SLOW DOWN, [2]HIGH SPEED SLOW DOWN, [3] REDUCE SPEED IN WORK ZONE, and [4] EXCESSIVE SPEED SLOW DOWN. Finally, *t* tests were conducted using the speed data obtained for the high-speed vehicles, and at a significance level of $\alpha = 0.05$, all of the messages were effective in significantly reducing the average speeds of those vehicles traveling 59 mph or faster in a 55 mph work zone when compared to MUTCD signing only.

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Nicholas J. Garber, Ph.D.
Professor, Civil Engineering Department, University of Virginia
and
Faculty Research Engineer
Virginia Transportation Research Council

and

Surbhi T. Patel, E.I.T.
Graduate Research Assistant

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ABSTRACT

Work zone speeds have customarily been regulated by standard regulatory or advisory speed signs. However, most drivers do not slow down in response to these *static* speed control measures. The changeable message sign (CMS) with radar unit has *dynamic* capabilities which may be more effective in altering driver behavior. The radar, attached directly to the CMS, determines the actual speed of individual vehicles in the traffic stream. Upon detecting a speed higher than a preset threshold limit, the CMS can display a personalized warning message.

This study evaluated the effectiveness of the CMS with radar unit in reducing work zone speeds. Four CMS messages designed to warn drivers that their speed exceeded the maximum safe speed were tested at seven work zones on two interstate highways in Virginia. Speed and volume data for the whole population traveling through the work zone were collected with automatic traffic counters. To assess the effect of CMS on high-speed drivers in particular, vehicles that triggered the radar-activated display were videotaped as they passed through the work zone.

Using the data obtained from the traffic counters and videotapes, speed characteristics were determined at the beginning, middle, and end of the work zone. These characteristics were computed for the whole population and for high-speed vehicles separately. Statistical tests were then conducted using these speed characteristics to determine whether significant reductions in speed accompanied the use of CMS.

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INTRODUCTION

With over 99% of the national interstate highway network infrastructure completed, emphasis now falls on rehabilitating and widening existing highways rather than constructing new ones. There are more and more construction zones on our highways. The number of accidents and fatalities in work zones rose significantly as spending on highway construction, mostly rehabilitation work along heavily traveled roadways, grew during the 1980s.[1] Work-zone deaths rose from 489 in 1982 to a staggering 783 in 1990 (Figure 1).[2,3] In 1991, 680 persons died in construction/maintenance zones, and work zone fatal crashes represented approximately 3.75% of all fatal crashes on interstates, freeways, or expressways in the United States.[3] Although the number of fatalities fell to 628 in 1992, this figure is still high. Safety in work zones is therefore a pertinent research topic.

Many studies have addressed vehicle accidents in work zones. Section 402 of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, which provides authorization for highways, highway safety, and mass transportation for the years 1992-1997, provides for annual reports to the Secretary of the U.S. Department of Transportation on the effectiveness of efforts by the states to reduce deaths and injuries at construction sites.[4]

Excessive vehicle speeds in the work zone are a major factor in crashes. In a study of work zones on Ohio's rural interstate system, Nemeth and Migletz found that high speed was cited 5.5 times more than any other factor causing accidents, and that the effectiveness of speed reduction signs should not be assumed.[5] In Texas, Richards and Faulkner concluded that speed violations resulted in 15% of non-work zone accidents and 27% of work zone accidents.[6] Humphreys et al. studied 103 work zones in several states and found that unsafe speeds in work zones and unsuccessful attempts at speed reduction were primary causes of work zone accidents.[7]

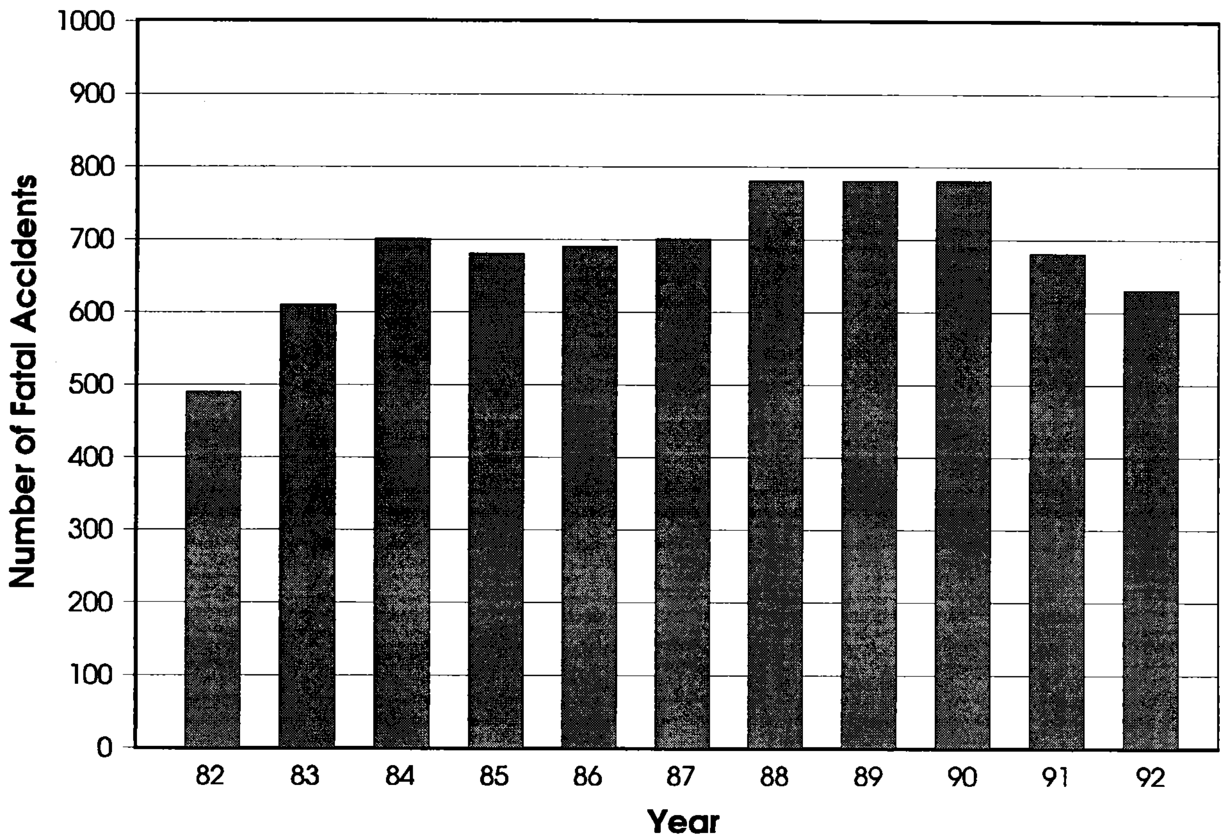

Figure 1. Fatal work zone traffic accidents in the United States between 1982 and 1992.
(Source: Fatal Accident Reporting System, National Highway and Traffic Safety Administration)

Until quite recently, work zone speeds were customarily regulated by the standard regulatory or advisory speed sign. Most drivers, it was found, do not slow down for static speed control measures.[8] Attempts to develop additional techniques to control work zone speeds include innovative flagging, law enforcement, and changeable message signing (CMS). All of these methods have been studied, and law enforcement, for example, has been found to be effective in reducing average speeds in the work zone by up to 13 mph.[9] However, both law enforcement and flagging can be very expensive in long-term projects, and limited availability of police officers, patrol cars, and trained flaggers, as well as safety concerns for the flagger and police officers, limit these two methods.

CMS has been of particular interest. Its dynamic capabilities provide the driver with reliable, accurate, up-to-date information. Since static signs do not effectively slow down drivers,[8] the dynamic component of CMS is critical to its speed control effectiveness. Drivers who receive real-time, actual information may be more inclined to slow down.

The dynamic qualities of CMS may be further improved by an information source like radar. Radar, attached directly to CMS, determines the speed of individual vehicles in the traffic stream. Upon detecting a speed higher than a preset limit, the CMS displays a preselected warning message to the driver. By personalizing this message to individual drivers, the radar-controlled CMS may be more effective than static signs. This type of speed control measure is aimed at a particular target group, the high-speed driver, and it will be important to note its effect on these drivers.

In the past, CMS has been successfully used in an informational and advisory capacity. In this new role, the sign is an excellent application of Intelligent Vehicle Highway System (IVHS) technology, providing credible real-time information based on the actual speeds of vehicles entering the work zone. As a speed control measure, the CMS with radar unit could provide safer roadway conditions and prevent many incidents due to driver inattention or excessive speed.

PURPOSE AND SCOPE

This project evaluated the effectiveness of CMS with radar for influencing drivers to reduce speeds in work zones, especially high-speed drivers. The project studied four different messages in several different environments to see the effect on speed profiles, described by characteristics such as average speeds, 85th percentile speeds, and speed variance.

The study was limited to work zones on interstate highways in Virginia. Only work zones calling for speed reduction were selected, and the work zones were studied only during daylight under dry weather conditions. The work zones were also chosen by the criteria of length, amount of traffic on the roadway, and the safety of the data collection team.

The specific objectives of the study were to:

- determine the speed characteristics of work zones on different types of highways using the standard signing specified in the *Manual on Uniform Traffic Control Devices* (MUTCD)
- determine the speed characteristics of the same work zones using both the standard MUTCD signing and CMS
- compare results and assess the effect of CMS on speed characteristics in the work zone
- determine the effect of CMS on the behavior of high-speed drivers, compared to the whole population
- determine to what extent and under what traffic conditions this technique will be effective.

METHODOLOGY

Literature Review

An extensive literature search identified publications addressing work zone traffic control and CMS. A manual search was conducted in the libraries of the Virginia Transportation Research Council and the University of Virginia, followed by a computerized search of the Transportation Research Information Service (TRIS) data base.

For background on methods of speed control in construction work zones, the literature search was divided into four major categories:

- assessment of need for speed reduction in work zones
- placement of speed control devices in work zones
- effectiveness of predominant speed control devices
- CMS testing and use.

The fourth category dealt with CMS technology and past research into its multiple uses. Existing studies mostly used CMS in an instructional or advisory capacity, rather than to regulate speeding vehicles by signalling individual drivers. Information on attaching CMS to a speed-detecting radar unit was lacking.

Assessment of Need for Speed Reduction in Work Zones

Philosophies of Speed Control

There are two general philosophies of work zone speed control.[10] The first is that work zone speeds should be similar to the posted speed limit of the highway, to minimize speed variations and thus accident potential. The second is that work zone speeds should be reduced since the area may contain traffic hazards. These basically contradictory concepts define a fundamental approach to work zone speed control: when it is impossible to safely accommodate traffic at normal speeds through a work zone, suitable measures should be taken to reduce speeds to the appropriate level.[11]

Common Misuses of Speed Control

The critical assumption in setting the work zone speed limit is that drivers will only reduce their speed if they see a real need to. One of the most typical misuses of speed control is setting an unreasonably low speed. If it is lower than drivers expect or will tolerate, they may not respect it. Another misuse of speed control is leaving reduced speed limit signs in place after the work is completed or when they are not needed. For example, when speed control is needed for the safety of workers adjacent to the travel lane, it is not necessary to leave the signs in place when work is not in progress. Leaving reduced speed limit signs in place when they are not necessary damages the credibility of speed control efforts.[12] In a study done in Georgia and Missouri, researchers found that motorists knew speed limits had been lowered in a work zone, but did not slow down unless they saw work under way.[13]

Determination of Need for Reduced Speed Limits

The speed limit in a work zone is designed to comply with the same basic safety principles used to establish the posted speed on the permanent roadway. Where possible, the design speed in the work zone as determined in the traffic control plan (TCP) should correspond to the posted speed limit of the highway, to maintain consistent driving conditions. If a reduction in speed is necessary, it is imperative to select a reasonable speed for that location.

The need for speed reduction must be addressed in the TCP, either by an engineering study or by the safety inspector. The reduction should decrease (1) the number and severity of work zone accidents, or (2) the potential for accidents where speed-related hazards exist.[12] Examples of hazardous conditions include:[12]

- Hidden or unobvious work-zone features (slight changes in roadway alignment, rough pavement surfaces, shoulder drop-offs)

- Reduced work-zone design speed (derived from factors such as stopping sight distance, high degree of curvature, and steep vertical alignment)

- Unprotected work space where a misdirected vehicle could encounter danger.

The following general conditions should be considered in the TCP when deciding on the need for speed reduction:[14]

- existing speeds on the roadway

- frequent or abrupt changes in roadway geometrics (lane narrowing, dropped lanes, and transitions from the main roadway)

- the existence of one or more of the hazardous conditions discussed earlier

- the logistics of construction operations (slow-moving, road-crossing construction vehicles; close proximity of construction workers and vehicles to through traffic).

Choosing the Appropriate Speed Control Method

The two methods of implementing the new speed limit are by reducing the regulatory speed limit, or by posting the maximum advisory speed. The regulatory method requires proper authority and permission, and is only feasible for long-term and long-distance construction projects. The more common procedure is to post the maximum safe speed, and it is crucial that the speed reduction be justified, and be imposed judiciously.

The MUTCD prescribes the appropriate signing procedure for regulating speed limits. Two of the signs used to indicate speed reductions are shown in Figure 2. The speed reduction can also be posted with a warning sign recommending the maximum safe speed through the work zone (see Figure 3). However, drivers do not always respond to work zone speed limit or maximum advisory speed signs.[13]

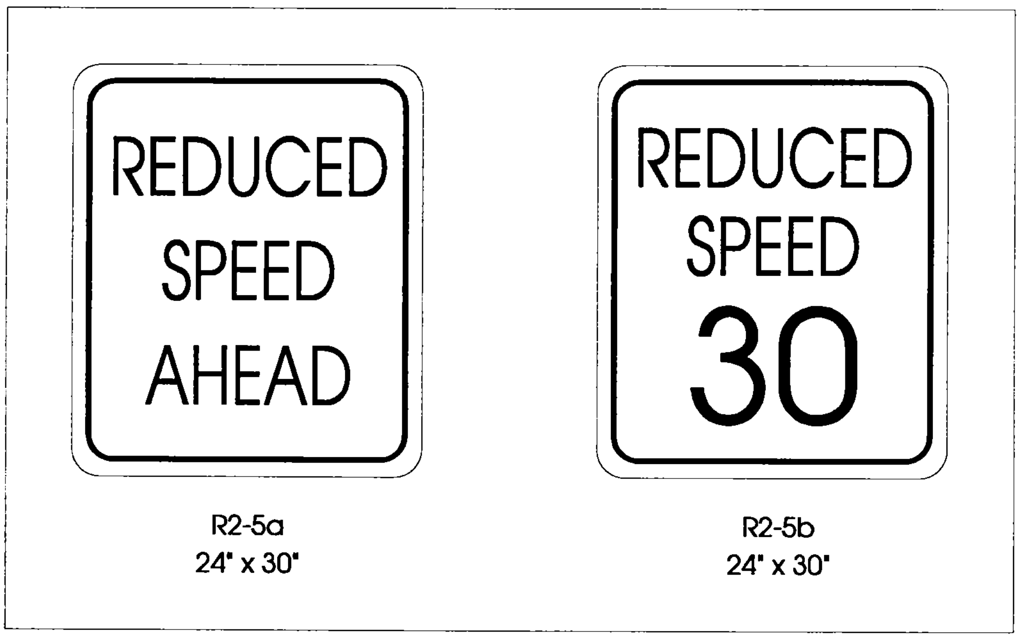

Figure 2. Standard speed limit reduction signs. (Source: MUTCD)

Passive versus Active Methods of Speed Control

Passive types of speed control like static signs are not always effective in altering driver behavior, and are usually only sufficient at sites with obvious hazards, where drivers have enough time and information to drive through the work zone without requiring special attention. Where the hazards are not obvious, drivers need active encouragement to reduce their speed. Active control generally consists of restricting movement, displaying real-time dynamic information, or enforcing compliance to a passive control.[12] Some of the more effective active methods include hand signaling devices like sign paddles and red flags, effective lane width reduction, law enforcement, and changeable message signs.

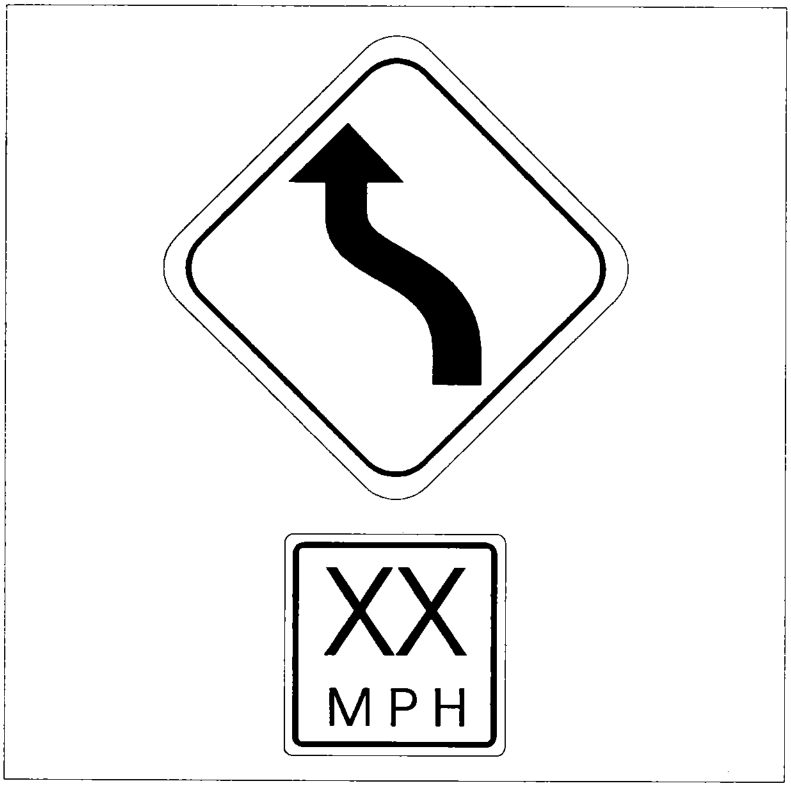

Figure 3. Advisory speed plate (W13-1) with warning sign for construction zones.
(Source: MUTCD)

The following factors can help select the appropriate device:[12]

- duration of potential hazard requiring speed control
- type of facility
- desired speed reduction
- overall cost of treatment
- institutional constraints (availability of CMS, police officers, patrol cars, and trained flaggers).

On long projects some of the active methods are too costly and might lose their effectiveness with time. In such cases the active method has been recommended for the opening days of the project and during major changes in conditions. Passive types of control are suggested at other times.[12]

Passive types of speed control apply to all types of highways and work zones.[15] Some active methods, on the other hand, have specific characteristics which may limit their use on certain types of facilities. For example, effective lane width reduction on multilane highways may disrupt traffic flow by reducing roadway capacity, causing localized congestion if traffic volumes are moderate to heavy. Flagging, law enforcement, and CMS are less problematic; like passive controls, they can be used on all types of highway facilities and work zones with little or no disruption to traffic flow. The only special requirement for these active methods may be additional flaggers, patrol car units, or signs on long sections.

Cost plays a large part in selecting a method. Most active methods tend to be very costly over time. Flagging and law enforcement can be relatively inexpensive for short durations, but high labor costs preclude long-term use. Effective lane width reduction, on the other hand, is expensive to implement for short durations, but relatively inexpensive for long durations. CMS is the only method that is relatively inexpensive in both the short and long term, since the equipment is purchased once and requires only routine maintenance thereafter.

The feasibility of a particular method may also depend on available manpower or equipment, such as trained and conscientious flaggers, police officers, patrol cars, or CMS. The method must also be feasible with respect to legal responsibilities, liabilities, and compliance to local, state, and federal regulations.

All methods of speed control, passive and active, have advantages and disadvantages. To select an appropriate device, all of the above factors should be considered during the planning phase of the work zone.

Placement of Speed Control Devices in Work Zones

Traffic Control Plan

A report published by the Federal Highway Administration[16] concluded that the main goals of the TCP are to allow the contractor to work efficiently while maximizing motorist and worker safety, minimizing traffic delays, maintaining existing or reduced operating speeds, and maintaining existing traffic flow rates. The TCP is included in the plans for a construction project, and shows the type and placement of traffic control devices for each phase or stage of construction.[16] The number, size and placement of the devices depend on five basic conditions: highway type, proximity of the work area to the travel lanes, prevailing traffic speed, the nature of the work activity, and the duration of the work.[17] The TCP specifies the appropriate devices and layouts in accordance with contracting procedures and specifications, and provides for the easy identification and replacement of inadequate and nonstandard devices.

Work zone traffic control may constitute up to 25% of the total cost of a project, and at times this cost may be too high for an agency to pay.[13] In such a case, the agencies are forced to make do with what they have available, and oftentimes the provisions for traffic control are left wanting. ISTEA has addressed the issue with a new law requiring the Secretary of Transportation to develop and implement a work zone safety program. Improvements in the area of safety should be achieved "by enhancing the quality and effectiveness of traffic-control devices, safety appurtenances, traffic-control plans and bidding practices for traffic-control devices and services."[4]

Evaluation of TCPs

The success of a TCP depends on how it is implemented and maintained during the construction project. In a study that evaluated TCPs at reconstruction sites,[18] a survey of TCP preparers revealed several parts of the process that needed improvement:

- field visits
- inspections
- feedback to TCP preparers
- field changes.

The survey showed that approximately two-thirds (or 62%) of TCP preparers are not present at the site when the traffic control devices are first installed. In addition, 40% said they seldom or never inspected the work zones to see if the TCP was performing as intended. It was recommended that TCP preparers visit the work zones to see how the TCP is performing.

In this survey, over 70% of the Texas District personnel interviewed said that more inspections are needed. However, discussions with field personnel revealed a sufficient number of inspections. Documentation was the problem. Considering the potential for tort liability in work zone accidents, written records or logs of daily TCP inspections or changes were recommended.

Inspections ensure the correct implementation of the TCP, and are especially helpful in identifying deficiencies in its design. For example, if a speed control effort was visibly inadequate, the TCP might be changed. Unfortunately, two-thirds of the TCP preparers said that they got no feedback from the field on how well their plan was working. The study suggested that if there is a problem or change in the TCP, the preparer should be notified. Also, if there is a need for a field change, the procedure should be more flexible. It reportedly takes 3 to 6 months for a field change approval, which suggests a need to change the procedures.

Generally, an adequate TCP is crucial to achieving appropriate work zone conditions, including speed reductions. For example, in an interchange reconstruction project, advisory speed signs with "odd-ball" speeds (such as 26 mph and 17 mph) were installed at several detour curves. Motorists noticed the speed signs and provided feedback, but did not slow down to the posted speeds. The project engineer concluded that the posted speeds were lower than the maximum safe speed, and thus lost their credibility.[18] For an effective speed control effort, the posted speed must be close to the maximum safe speed.

Another study conducted in Alabama by Auburn University researchers[19] assessed the effectiveness of traffic control plans at construction work zones. In three work zone sites (two rural, one urban), the study found:

- a lack of advisory speed signs at warranted locations
- motorist confusion due to the large number of traffic control devices competing for attention
- improper placement of some traffic control devices
- inconsistencies between advisory and regulatory speed limit signs.

The study stated that advance warning signs had inconsistent effects on motorists' speeds. For example, excessive traffic control devices on construction projects can reduce the effectiveness of individual devices. Advance speed signs were also not effective unless drivers considered the speed reasonable for that location.

Variances like visible construction activities, sight distances, lane changes, and detours were critical in causing speed reductions. The study recommended using advisory speeds only when necessary, selecting advisory speeds consistent with site conditions, avoiding the overuse of traffic control devices, and supplementing the guidance with a more positive means of controlling driver behavior.

Motorist Response to Various Speed Control Efforts

A survey[20] of motorists in four states to determine how they react to construction zone signs confirmed many of the Alabama findings. This study showed that approximately 52% of the drivers entering a construction zone with appropriate speed control devices did not reduce their travel speed immediately. For example, 50% of the drivers said they would slow down for a sign marked "ROAD CONSTRUCTION AHEAD," but after actually seeing the workers, 94% said they would slow down. This is a substantial change in response from that achieved by the static sign.

One particular recommendation was that construction signs need to be more specific, with more human elements, to effectively control drivers' behavior. CMS with radar addresses that concern. It can identify specific speeding vehicles and display appropriate messages to the individual drivers.

A survey of 58 drivers in three work zones in Missouri and Georgia assessed their understanding of work zone traffic control.[21] At one site, the work was conducted off the traveled way, but the other two sites required right lane closures. Ninety-one percent of the drivers said that they saw the speed-limit sign and slowed down because of the reduced work zone speed limit. The survey showed that drivers do understand work zone signing and traffic controls; however, they do not believe the speed limit should be reduced when there is no work or when work is off the traveled way. The study also suggested that drivers receive specific messages about speed and distance to the work area (CMS can perform such a function).

Benekohal et al.[22] surveyed 441 drivers in Illinois to determine their understanding of and reaction to work zone traffic control signs. Only about 60% of the drivers said they drove at or below the work zone speed limit, and only about 54% said that the work zone was more hazardous than non-work zone areas. It is important to increase the awareness of drivers to the danger of work zones and the need for traffic control. CMS, with its dynamic capabilities, may be the means to achieve this end on site.

Effectiveness of Predominant Speed Control Devices

Identification of Predominant Speed Control Devices

Flagging (MUTCD and innovative) and law enforcement, two predominant active methods of speed control, have been found very effective.[8,11,12,14,23,24] Assessing and comparing flagging and law enforcement with CMS (as used in previous studies) revealed that CMS has similar capabilities and may in the long run be more advantageous and convenient. CMS combined with a radar unit may prove to be an even more effective speed reduction device.

The range of speed control devices is not limited to these three methods. Other methods include lane width reduction, rumble strips, transverse striping, radar transmitters, conventional regulatory and advisory speed signing, and more. The effectiveness of these methods has not been as pronounced as for the above three, but under some conditions they provide speed reducing benefits.[25]

Flagging

Flagging uses hand signaling devices, such as sign paddles and red flags, to alert drivers of hazardous conditions. The sign paddles, indicating "SLOW" or "STOP," are more effective because they provide more information and positive guidance to drivers, while the red flag only indicates caution in general.[14] The red flag can also cause confusion, as the driver is not always aware of the type of warning being given. Hand signals can accompany these signs to guide traffic through the work zone. For example, innovative flagging incorporates hand signals to enhance regular flagging; the flagger motions traffic to slow with the free hand, then points to a nearby speed sign.

Richards et al. studied flagging (both innovative and MUTCD)[24] at six work zone sites, and found that this procedure could reduce work zone speeds by an average of 19%. However, the flagging method requires specially trained personnel and high labor costs, especially when more than one flagger is required or when the project lasts a long time. A third disadvantage is the flaggers' safety, particularly at night. This method is not commonly used on high volume multi-lane highways as it is unlikely that all motorists, in particular those on the middle lanes, will see the flaggers.[24]

Law Enforcement

The use of law enforcement officers at the site has been found to be more effective than flaggers in reducing vehicle speeds.[23] There are two variations of this type of enforcement: a stationary police cruiser with lights and radar on, and a police traffic controller. The latter is less effective since the uniformed police officer only stands at the side of the road, near a speed limit sign, and manually motions the traffic to slow down. In this case, the officer provides no real threat to drivers, whereas with the stationary patrol car, the drivers slow down to avoid being given a ticket for speeding. For maximum effectiveness, the patrol car should be highly visible to approaching traffic, and although it may occasionally pursue a speeding vehicle, it should generally remain stationary. As a further incentive, many state legislatures, including Virginia and Pennsylvania, have automatically doubled all fines for traffic violations in work zones.[13]

Richards et al.[24] also studied the effectiveness of this method in their work zone speed control evaluation. They found that a stationary patrol car with a law enforcement officer resulted in an average speed reduction of 18%. However, the study also concluded that a circulating patrol car was ineffective. In order for the law enforcement technique to be effective, the police officer must be present at all times, and at some long work zones more than one officer may be needed. Thus, while this method is also very effective, there are many deterrents. There is limited availability of police officers and police cars, the agency or contractor does not have direct control over their performance, the cost is high for long-term and long-distance work zones, and enforcement is difficult on multi-lane urban facilities.

Comparison of Three Methods

Richards and Dudek[12] compared flagging, law enforcement, and CMS in a study of work zone speed control measures. They found that flagging and law enforcement are both suitable for all types of highway facilities, and have similar advantages in that they are relatively inexpensive in the short term and relatively quick and easy to implement and remove, with little or no disruption to traffic flow. CMS has similar advantages, but is also suitable for long-term applications, and is effective at night and in inclement weather. Other advantages of CMS cited by Richards included direct control by the contractor over its use, and no manpower requirement, averting high labor costs and management responsibilities.

Past studies have revealed that flagging, law enforcement, and CMS all exhibit some speed-reducing effect.[8,11,12,14,23,24] However, all of these studies based their results on overall or average speed reductions of vehicles in the traffic stream. They did not provide any distinct information on the effectiveness of the CMS, or any other method, on influencing the behavior of those driving at speeds in excess of the posted or advisory speed limit.

High-speed drivers are the main group toward which speed control efforts are directed. The lack of specific information on the effect of speed control methods on their behavior may be a major deficiency in prior studies. This critical factor is especially emphasized in this study. The effect of CMS with radar unit on the drivers of speeding vehicles, as opposed to all vehicles, is examined separately and in detail by tracking each high-speed vehicle through the work zone. Rather than downplaying the actual force of the speed control method by assigning average values of speed reduction, the effect of the method on high-speed drivers is particularly discernible.

CMS Testing and Use

General Advantages of CMS

The CMS is critical on high-speed highways as it provides drivers with accurate, up-to-date information advising them of problems and unexpected conditions and telling them the best course of action.[26] It can display information and warnings, and change in response to changing conditions in the area. For example, during inactivity the sign can be blanked, but during construction the sign can be programmed to display pertinent information. In addition, the portable CMS can be moved to critical locations in work zones.[26]

Generally, motorists are more likely to respond to messages and speed advisories based on real-time conditions, and this is the greatest benefit of the CMS. Its primary purpose has been advising drivers of unexpected traffic and routing conditions and special applications, for example special speed control measures.[26]

Effectiveness of the CMS

In a study of CMS effectiveness at freeway construction site lane closures, Hanscom[27] concluded that CMS tends to improve traffic flow and reduce speeds, which is safer for construction workers. Hanscom conducted before-and-after studies of CMS application versus non-CMS application at freeway construction sites with lane closures to assess the effectiveness of the CMS on operational traffic behavior. From examination of traffic performance and driver interview data regarding detection, comprehension, and interpretation of the sign, CMS consistently resulted in increased preparatory lane-change activity, smoother lane-change profiles, significantly fewer late exits (within 30.5 m (100 ft) of closure), and reduced speeds at the lane closure point. In particular, speed reductions were associated with speed advisory messages under most circumstances. Hanscom[28] and Webb[29] both found that CMS, used for advance warning at lane closure work zones, reduced average speeds by up to 7 mph.

Richards et al.[24] found that both a "Speed-Only Message" and a "Speed and Information Message" reduced mean speeds in the range of 0 to 5 mph. The results from both types of messages at 3 freeway and urban arterial sites showed speeds reduced from 3% to 9%, and on average reduced by 7%.

Benekohal and Shu[30] also studied the effect of CMS displaying speed limit and information messages inside a work zone. Two alternating messages were displayed on the CMS, "WORKERS AHEAD" and "SPEED LIMIT 45 MPH," and three experiments were conducted during the course of the study. The first placed the CMS in advance of the work zone. Results from this experiment showed that the average speeds of both cars and trucks reduced significantly. The second experiment placed the CMS within the work zone, and the average speeds of cars did reduce near the CMS, but it was no longer effective away from the CMS. Truck speeds, on the other hand, did not reduce near the CMS, but decreased notably away from the CMS. In order to examine the lasting effect of the CMS, the third experiment used two CMS within the work zone. It was found that this configuration effectively reduced the average speed of cars and trucks at both locations within the work zone.

The study concluded that the messages affected cars close to the CMS, while the impact on trucks took place further from the CMS. The net speed reductions seemed to depend on the travel speed of the vehicles, particularly for cars. To assess this effect, it was recommended that further studies be conducted to establish the relationship between speed reduction and velocity of vehicles.

This study addresses this particular issue. In all of the studies reviewed, no specific information was obtained on the effect of CMS on vehicles traveling at speeds higher than the posted or advisory speed limit. As this group is the main target for speed control, it is imperative to single out these vehicles and study their behavior and response to the speed control effort. Average speeds for the population cannot provide the necessary information. This research attempts to determine the effect of CMS on high-speed vehicles and determine the relationship between speed reduction and velocity of vehicles.

Effectiveness of Radar-Controlled Speed Sign

The Minnesota Department of Transportation (MnDOT) conducted a work zone speed limit demonstration[31] to study the effectiveness of various speed control methods. One active sign employed by MnDOT was similar to the equipment used in this study -- a radar controlled sign that detected the motorists' speeds. The difference between the two signs was that the MnDOT sign displayed the vehicle's speed, while in this study the sign displayed a preselected message.

Results showed that there was an 85th percentile speed of 68 mph in the control condition when no speed limit signs were displayed, and 61% of the drivers were in the 10 mph pace (the 10 mph speed range that contains the greatest percentage of observed vehicle speeds). When the static speed limit signs were used, there was a reduction of the 85th percentile speed to 58 mph, and the percentage in the pace dropped to 51%. While there was a reduction, this speed was still 18 mph over the 40 mph posted speed limit, and speeds were actually more variable, as indicated by the percent in the pace. The results from the radar controlled sign were more favorable. The 85th percentile speed, although still higher than the 40 mph posted speed limit, was reduced to 53 mph, and the radar activated sign was also more effective than the static sign in significantly reducing the percentage of drivers under 60 mph. The static sign had approximately 14% exceeding 60 mph compared to only 1% while using the radar-controlled sign. In addition, the active sign increased the percentage of drivers in the 10 mph pace to 65%.

One of the major contributors to accidents in work zones is a large speed differential among vehicles, especially in work zones where the speed limit has been reduced.[32] Several studies have determined a recognizable trend between travel speed and accidents. Solomon[33] and Cirillo[34] established empirical relationships between the two factors and determined that fatality rates were highest at high speeds and lowest at about the average speed. In addition, Garber and Gadiraju[35] determined that accident rates, on both freeways and arterials increased as speed variance increased. Garber and Woo,[36] in their study of accident characteristics in work zones in urban areas, found that there were generally increases in speed variances during the periods the work zones were installed. They also found that the accident rates during the construction period were significantly higher than those before the work zone was installed. Thus, if more vehicles can be brought into the pace, conditions might be safer and less conducive to accidents.

One of the main purposes of the CMS with radar unit is to identify and single out high-speed vehicles in order to alert individual drivers to the hazardous area. These vehicles may have radar detectors which can alert them of the speed zone cause them to slow down. The detector warning is then reinforced with the personalized message that flashes up on the CMS. Using this tactic, more drivers may be brought into the 10 mph pace, thereby resulting in overall safer conditions in the work zone.

Effect of Radar in Work Zones

The MnDOT study[31] found from visual observations that a high percentage of vehicles would hit their brakes just after the radar signal was detected. These drivers were presumed to have a radar detector, and were observed checking their rear view mirrors and around the area to locate a possible hidden patrol car. This resulted in their deceleration, as well as the deceleration of the group of drivers immediately behind the vehicle. While this reaction does succeed in slowing down the vehicles, a major concern has been whether the sudden deceleration of these vehicles may result in an increase in vehicle conflicts or accidents.

Ullman[37] conducted a study to determine the effect of using radar transmissions to reduce speeds without visible enforcement present. The radar was tested as an attention-getting device to increase the awareness of drivers as they entered the work zone. The study also addressed the concern that conflicts might occur between vehicles with detectors, who may decelerate suddenly when the radar signal is received, and those vehicles without detectors.

Results showed that the radar signal had the effect of reducing speeds in the work zones by approximately 2 to 3 mph. The radar had a greater effect on trucks, in comparison with automobiles, as the use of radar detectors is more widespread among truck drivers.[38] In comparison to the entire vehicle sample, the high-speed vehicles (> 65 mph) were also found to be more affected by the radar transmission. With regard to increased conflicts, the results showed that the conflict rate increased slightly, but as a whole, the increase in total conflicts was not found to be statistically significant.

Benekohal et al.[39] also studied the effectiveness of drone (passive or unmanned) radar on reducing vehicle speeds on rural interstate highway work zones. Three experiments were conducted. The first evaluated the effect of the radar when applied at the beginning of the work zone for a short period of time. The second and third experiments used one and two radars, respectively, applied for a longer period of time in order to assess the lasting effect of continuous signal transmission.

Results showed that the drone radar can be effective in reducing speeds of high-speeding vehicles which have radar detectors. However, it was found that its effectiveness diminishes over long periods of time as drivers find out that it is not a police radar. In order to maximize its effectiveness, it was recommended that the location of the radars be selected to provide the maximum threat of police presence, and they should not be easily identifiable by drivers.

Implementation of CMS with Radar Unit

The CMS device with radar unit tested in this study has the potential to be an effective speed control method. As the radar unit is attached directly to the CMS, its location is concealed and may not be easily recognized. Thus, it has the potential to influence drivers to reduce their speeds in one of two ways: (1) by alerting high-speeding drivers using radar detectors of possible law enforcement officers in the area, and (2) by flashing a personalized warning message to all of those vehicles exceeding the established threshold speed. By combining the effect of the radar and the personalized message, the impact on driver behavior might be more forceful, evoking a greater response to the speed control device.

One of the major contributors to accidents in work zones is a large speed differential among vehicles.[32] While CMS with radar attempts to isolate particular vehicles and slow them down, the reduction of their high speeds may result in a larger 10 mph pace, diminishing speed differentials in the work zone and possibly lowering accident potential.

Consideration should be given to where the CMS with radar is placed within the work zone. It should be located where a real need is perceived, so drivers will be more apt to respond. The sign should be placed to avoid confusion or distraction; excessive signs can negate the effect of such a device. Finally, CMS should be removed when work is stopped for the day. Attention to these details is imperative to prevent misuse of the device and achieve the greatest response.

While CMS has generally been used in the past for informational or advisory purposes, this study has proposed that it be used in a different approach. This new application incorporates CMS as a special speed control measure that may use one of several messages on the display to influence speeding drivers to reduce their speed in the work zone. By testing the sign in actual work zones, its effect was examined and recommendations were made for its use as a standard speed control method.

Data Collection

Identifying Suitable Work Zone Study Sites

The selection of suitable work zones was crucial. Initially, information on anticipated maintenance and reconstruction activities throughout the state of Virginia was requested from resident engineers by distributing a survey letter. The survey (see Appendix A) requested information on the project location and also a description of specific characteristics of the work zone, for example, day or night operation, the number of lanes to be closed, and the length of the work zone. If the work zone appeared feasible during this preliminary evaluation, a site visit was warranted and it was submitted for the final selection process.

To be suitable for data collection, the work zone had to meet the following qualifications:

- The length of the work zone had to be at least 457.2 m (1,500 ft) or more to allow drivers who wished to vary their speeds along the study area to do so.
- As congested flow usually predominates on highways with high average annual daily traffic (AADT), the estimated free flow traffic on the highway in question had to be at least 30% of the total traffic. This condition allowed the monitoring of the individual speeds of a sufficient number of vehicles being driven at the drivers' desired speeds.
- The work zone had to be able to safely accommodate the CMS equipment and researchers without interfering with construction vehicles and workers or obstructing the flow of traffic.

Seven sites were selected for data collection (Table 1). All of the sites were interstates as no feasible sites were identified on the primary system. Three work zones were studied in August, September, and October 1992: I-81 South near Lexington, I-64 East near Covington, and I-64 East near Short Pump. Data collection was discontinued during the winter months. The remaining four sites were completed between May 1993 and November 1993. Appendix B shows a typical work zone study area.

Speed and Volume Data: Automatic Traffic Counts

The procedure for preparing sites for data collection was stringent. A whole day at the work zone was devoted to laying the groundwork and arranging for the data collection. The first step was laying down the pneumatic tubes and automatic traffic counters (StreeterAmet 141A traffic counters) to collect speed and volume data for all vehicles traveling through the work zone. These were collected continuously, day and night, to provide the appropriate data without the CMS as well as with the CMS during actual videotaping and sign display.

Table 1. Work Zone Study Sites

ROUTE NUMBER	NEAREST CITY OR TOWN	COUNTY	1991 AADT	NUMBER OF LANES	NUMBER OF LANES OPEN TO TRAFFIC	NORMAL SPEED LIMIT	POSTED SPEED LIMIT	TYPE OF WORK ZONE	DATES OF STUDY
81 South	Lexington	Rockbridge	24,000	2	1	65	55	Rockslide Damage Control	8/18-8/21/92 8/25-8/26/92
64 East	Covington	Alleghany	8,400	2	1	65	55	Bridgedeck Repair	9/14-9/16/92
64 East	Short Pump	Henrico	25,000	2	2	65	55	Construction of Additional Lane	10/26-10/29/92
81 North	Bristol	Washington	33,000	2	2	65	55	Bridge Reconstruction to meet standards	5/24-5/27/93
81 North	Abingdon	Washington	24,000	2	1	65	45	Bridge Reconstruction & Complete New Interchange Construction	7/12-7/14/93
81 South	Abingdon	Washington	24,000	2	1	65	55		8/23-8/26/93
64 East	Shadwell	Albemarle	21,000	2	1	65	55	Concrete Joint Repair	11/1-11/3/93

The tubes were set down at the following three locations within the work zone:

1. at approximately the beginning of the work zone (station 1)

2. at approximately the midpoint of the work zone (station 2)

3. just before the end of the work zone (station 3)

These three locations were chosen because at the entrance to the work zone vehicle speeds are usually those preferred by the drivers, in the middle of the work zone vehicle speeds may be influenced by the speed control effort, and at the end of the work zone drivers may choose to regain speed believing that they have passed the monitored area.

After the first day of setup, speed and volume data were downloaded regularly from the counters in the morning before data collection began for the day, and at the end of the afternoon on the last day at the site. The StreeterAmet T240 programmer (TrafiComp II) which was used to program the counters initially was also used to collect the data from the counters (Figure 4). At the end of each day, the data were then downloaded onto disk using a laptop computer connection.

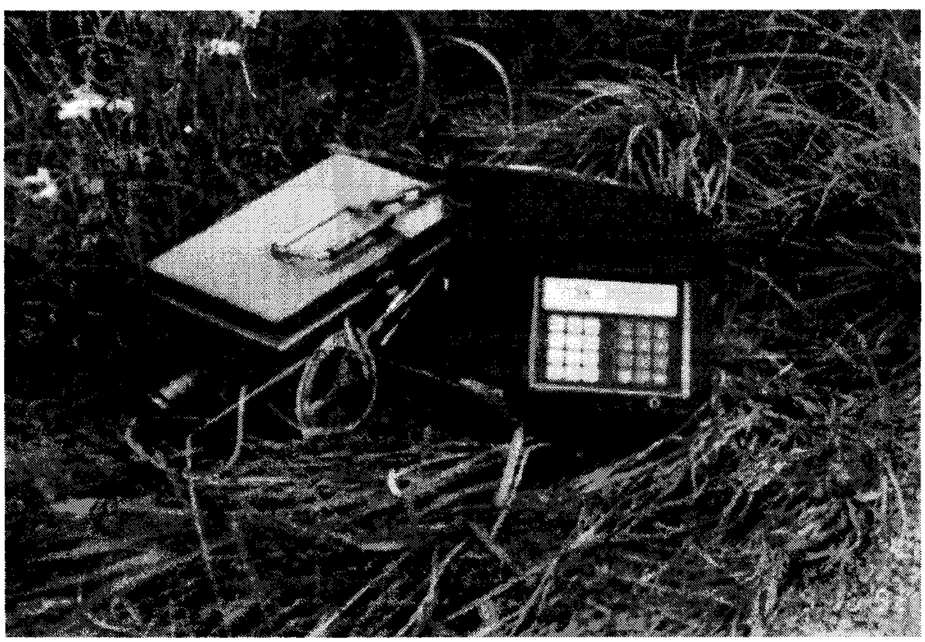

Figure 4. Traffic counter (left) with T240 programmer.

Several problems were encountered with the pneumatic tubes and counters during data collection. High traffic volume, high speeds, and high temperatures (the data were collected during the summer) were all contributing factors to possible tube failure, which impeded speed data collection. These failures took three forms: 1) a hole in the tube, 2) the dislodging of the tube as the nails driven into the asphalt were torn up, or 3) the destruction of the tube itself by tearing into two pieces. In order to avoid an excessive loss of speed data, the site was checked regularly and damage control was maintained resolutely; but the loss of some data was inescapable.

Damage to the tubes was reversible and more easily discovered than the problems with the counters. On a few occasions, the counters malfunctioned and did not retain the speed data in memory. This problem could only be detected when the data were downloaded, and lost data were irreplaceable. This problem occurred very rarely; but gaps in the data created some impediment during the data analysis stage of the project.

Data Collection with CMS

Placement of CMS

The CMS was placed a short distance behind the first set of tubes (at the beginning of the taper if vehicles were channelized into a single lane) to detect vehicle speeds as they entered the work zone. The CMS used in this project was specially designed for the study. It used the standard message display board (CMS-T300, American Signal Company), but the radar unit attached to the side was a special feature (Figure 5). This radar (TRACKER TDW-10 Wide Beam Vehicle Detector) was connected to the central processing unit that controls the functions of the message board, and could be used in conjunction with the message display. In other words, if the radar was activated and it detected a speed higher than a preset threshold speed, then the message display could be programmed to flash a particular message instantaneously.

Figure 5. Changeable message sign with radar unit.

The radar was positioned to point at vehicles as they entered the work zone at a range of 91.4 m to 182.9 m (300 to 600 ft). Generally, the main objective was to direct the radar to a point where only one vehicle's speed would be detected by the radar. The purpose of this particular arrangement was twofold. First, when the radar detected a speeding vehicle, an observer was able to identify that particular vehicle, take note of its key characteristics (color of vehicle, vehicle type) and then relay this descriptive information over the walkie talkie to the crew staffing the video cameras. At the same time, the driver of the vehicle would be in range of the message as it came up on the display and then be able to act accordingly if he or she so desired.

Marking the Study Areas

At the second and third sites (near stations 2 and 3 where the counters were placed), additional tubes were set down marking a distance of 45.7 m (150 ft). These tubes were used to designate a section of known distance in order to calculate the speeds of those vehicles for which the message was activated. The cameras provided the means to determine the vehicles' travel times across the sections as their movements were recorded on film. By knowing the time and the distance, the speeds of the vehicles at these two locations in the work zone were calculated.

In the first data collection effort, the tubes on the pavement were difficult to see on videotape. The lighting and the similarity in color of the tubes and pavement made it hard to pinpoint exactly when the vehicles' tires crossed over the tubes. Large orange cones were placed at the edge of the pavement next to the tubes to act as elevated markers, but the camera angle was inadequate for the cones to clearly define exact entrance and exit points within the study area. At the second and third work zone sites, an attempt was made to distinguishing the tubes with white roadway marking tape. These tape markings did not further aid in visibility.

To solve the difficulty of seeing the tubes, an air-pressure-activated light-emitting diode (LED) display was constructed. The lighting device was attached to each of the tubes marking the entrance and exit of the 45.7 m (150 ft) sections. The light was activated when the tire exerted pressure on the tubes, clearly indicating when each vehicle's front wheels entered and exited the study area. The light did not in any way distract or endanger drivers, as it was placed off of the traveled way and faced the opposite direction of travel. This method was quite successful and was used for data collection at the remaining four sites.

A study area can be seen clearly in Figure 6. The first light was activated as the vehicle's front tires crossed over the first tube. The tube is also marked with a large orange cone. While the light looks rather grey in the figure, in the videotape it appeared as a bright red flash that was easily detectable. Further back, 45.7 m (150 ft) behind the first set of tubes, a second cone and light fixture, although not activated, can also be seen.

Placement of the Video Cameras

As the speeding vehicle entered the work zone, its progress was monitored by the two camera operators. Each camera was pointed in the direction of oncoming traffic so as to record each speeding vehicle on film as it crossed over the tubes marking the respective 45.7 m (150 ft) study sections (Figure 7). The two cameras were placed a relatively wide distance apart to capture any change in speed as the vehicles traveled along the roadway. If a speeding vehicle slowed down in response to the sign, this reduction would be noted by the first camera (station 2). By the time the vehicle reached the second camera (station 3), its speed might be the same or lower, as the driver responded to work zone conditions. The speed also might have risen again; the impact of the speed control effort may have lost force as drivers traveled further down the work zone. With strategic camera placement, driver behavior, as well as the effectiveness of the speed control device, was studied.

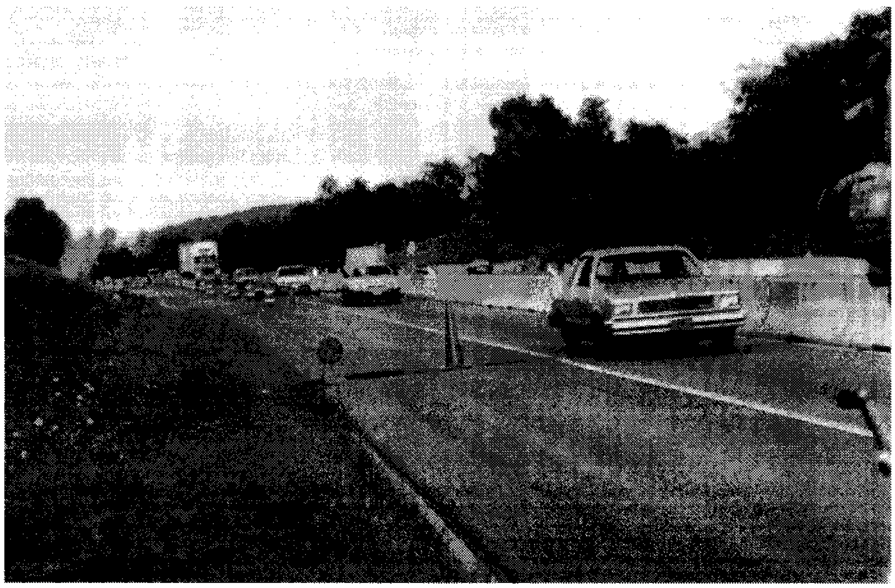

Figure 6. 150-foot study area.

In addition to videotaping, the second camera operator also collected manual data on each vehicle. The second camera was fairly distant from the CMS where the speeding vehicle was identified, leaving enough time before the vehicle came into range of station 3 for the data collector to complete a standard predesigned form (Appendix C). Information on the type, color, size, and make (if time permitted) of the vehicle, was marked on the data collection sheet to help identify each vehicle on the videotapes during data reduction.

Data Recording with CMS

After all equipment and markings (traffic counters, CMS, and video cameras) were set up at the appropriate locations, the only task that remained was the actual videotaping and collection of speed data for individual vehicles using the CMS. After arriving at the site in the morning and downloading the speed and volume data from the traffic counters for the day before, each of the stations was set up and the data collection team took their positions. Each time a speeding vehicle triggered the automated speed display, the observer at the CMS identified the vehicle and relayed the descriptive information to stations 2 and 3 so the progress of that specific vehicle could be monitored through the work zone by videotaping it.

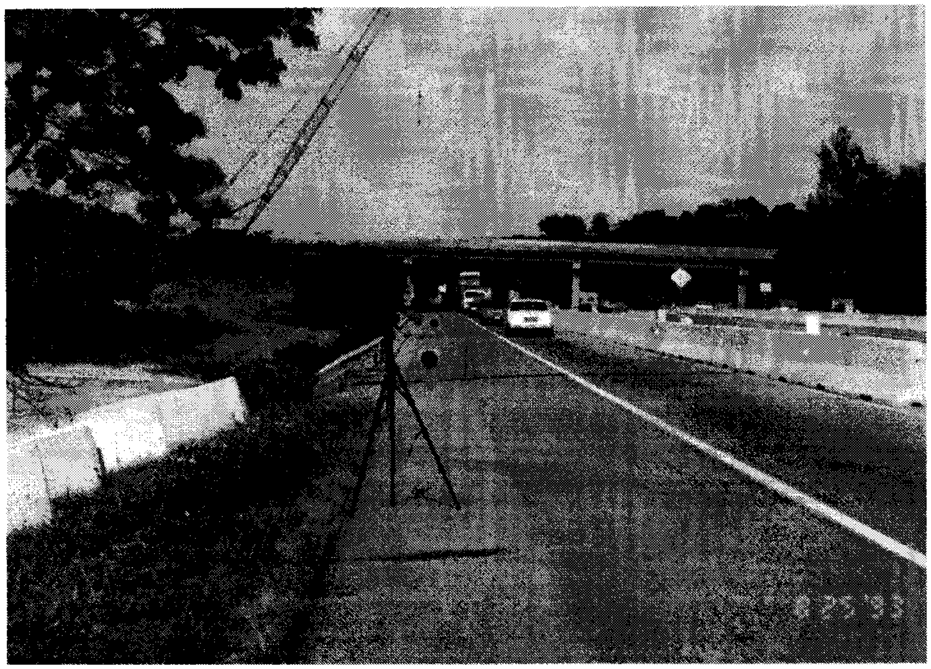

Figure 7. Placement of cameras with respect to 150-foot study area.

Several considerations went into selecting the actual messages used on the CMS. First, the variety of messages to be tested was limited by the fact that the CMS only displays three lines of text, with a maximum of 5 characters per line using the largest font size and a maximum of 10 characters per line using the smallest. Second, discrete (also known as static) messages, in which only one screen is used to relay the information, are more desirable than rolling or sequence messages, in which more than one screen is read by the driver.[40] As a single message being flashed on the screen would probably be more surprising and draw more attention, this factor was duly noted and observed when creating the messages. Finally, the last determinant was the fact that motorists usually prefer simple messages.[40] This particular guideline actually conformed with the intent for the messages to be personalized, brief, and to-the-point. Considering all these criteria, the following four messages were developed and tested at each site:

"EXCESSIVE SPEED SLOW DOWN"
"HIGH SPEED SLOW DOWN"
"REDUCE SPEED IN WORK ZONE"
"YOU ARE SPEEDING SLOW DOWN"

The largest font size which would fit the text on the display was used. Some lines of text were thicker than others, depending on how many letters were required. An example of some of the different font sizes can be seen in Figure 5. As shown in the figure, the words HIGH and

SPEED were each assigned the largest font size, 7 x 7 (Bold), on two separate lines, and SLOW DOWN was displayed using the narrowest font, 3 x 7, in order to use the maximum of 10 characters on a line. All of the messages are shown below, as they were displayed on the CMS, with the font size used for each line on the board. The first number represents the width of the letter, and the second number represents the height, 7 disks, which is the same for all of the fonts.

EXCESSIVE (3 x 7)
SPEED (7 x 7)
SLOW DOWN (3 x 7)

HIGH (7 x 7)
SPEED (7 x 7)
SLOW DOWN (3 x 7)

REDUCE (5 x 7)
SPEED IN (4 x 7)
WORK ZONE (3 x 7)

YOU ARE (5 x 7)
SPEEDING (4 x 7)
SLOW DOWN (3 x 7)

Note that the 7 x 7 Bold is the only font that doubles the thickness of the letters to two columns of disks for each stroke. The remaining three font sizes all produce letters with a thickness of only one disk; however, the overall width of the letters on the board ranges from 3 to 5 disks.

The threshold speed for the automated speed display was set at 3 mph above the work zone speed limit. As a rule of thumb, a minimum of 200 speeding vehicles were taped for each message at each site. Under normal conditions, the data collection for one message could be completed in approximately 2-3 hours. Exceptions to the 200 vehicle minimum were made in areas that had a low Average Annual Daily Traffic (AADT) and could not maintain the high volumes necessary to obtain 200 speeding vehicles in a reasonable amount of time. Under these special circumstances, a minimum of 150 vehicles were taped for each message (this minimum was applied at I-64 East in Covington). Speed and volume data were also collected by the counters while the CMS was in operation, but without the cameras and observers, in order to evaluate the impact of their presence, especially at stations 2 and 3, on the reactions of the speeding drivers and consequently, on the effectiveness of CMS.

Compiling Speed and Volume Data from Traffic Counters

Using the StreeterAmet T240, speed and volume data were extracted from the traffic counters daily. Initially, the counters were set up to collect data in 10-minute intervals to allow a direct correlation of traffic counter data with the manual data collected during videotaping. However, the counter had a limited memory storage space, and when it reached its threshold, data collection stopped. In order to leave the counters running overnight without losing data, the interval was changed to one hour.

Using the data from the automatic counters and the speed data obtained manually from the videotapes, a detailed analysis was carried out for (1) the period during work zone activities but prior to the installation of the CMS, (2) the period during which the CMS was in operation with the video cameras and data collection team present, and (3) the period during which the CMS was in operation but without the video cameras and data collection team present. Differences in speed characteristics for the different conditions were determined by comparing the average speed, 85th percentile speed, and speed variance downstream of the CMS.

Extracting Speed Data from Videotapes

Reducing the data from the videotapes was a very labor-intensive and painstaking task. A 3/4" editing system was used for this process, but first the normal 1/2" videocassettes that were used in the video cameras had to be converted to professional 3/4" tapes. The 3/4" editing system has the capability of slowing frames down to one thirtieth of a second. The movement of the frames is managed by a jog control that allows forward and reverse frame-by-frame adjustments.

The timing on the video equipment is recorded on a control tracker, which maintains accuracy to ± 2/30th of a second (two frames). The following procedure was used to determine each vehicle's travel time:

1. The jog control was used to manipulate the position of the vehicle's front tires until they rested on the first tube.

2. This input time was programmed into the machine.

3. The jog control was then used to forward the frames until the vehicle's front tires rested on the second tube, 45.7 m (150 ft) past the first tube.

4. This output time was programmed into the machine.

5. Automatically, the program calculated the difference between the input and output times to provide a vehicle travel time, in thirtieths of a second.

This procedure was carried out for all of the vehicles at both stations 2 and 3 for all of the messages at each site. Over 10,000 vehicle travel times were computed in this manner.

As noted earlier, it was difficult to clearly define the points where the vehicles crossed over the tubes at the first three sites. Thus, in order to ensure accuracy, each vehicle was checked twice; if the two times were within ± 2/30th of a second, then the first value was taken as the time to traverse the section. If the two times were not within ± 2/30th of a second, then the process was repeated until the desired accuracy was achieved. This procedure ensured that the error did not exceed ± .55 km/h (± .34 mph) for the lowest speeds or ± 4.9 km/h (± 3.03 mph) for the highest speeds that were calculated at these three work zones using the determined travel times. These two figures were computed using the extreme conditions at the three sites and it should be noted that the speeds used to estimate these errors occurred very rarely. Thus, the mean error would be more applicable to describe all of the data, and this error was computed to be ±2.7 km/h (± 1.66 mph). The comparison of the data for the different conditions was not affected as the same methodology and accuracy was used at each of the three sites.

At the remaining four sites, it was possible to use the LED lighting device, which made it easy to determine the exact time the front wheels of the speeding vehicle crossed over the tubes.

In order to determine whether the data obtained from the sites using the tubes only was comparable to that obtained using the lighting device, significance tests between the two types of speed data were conducted using analysis of variance. First, the change in speed between the three stations (1 & 2, 1 & 3, and 2 & 3) was computed for each vehicle at each site. Second, the speed changes were grouped into three categories: the percentage of vehicles reducing speed by 0-4.9 km/h (0-3.0 mph), 5.0-9.7 km/h (3.1-6.0 mph), or 9.8 km/h (6.1 mph) and greater. All of the data for each site were stored separately from those for the other sites. These percentages were then used for the analysis of variance. The percentages obtained at the sites using the tubes only were compared to the percentages obtained using the LED lighting device.

Nine significance tests were conducted -- each of the three speed categories 0- 4.9 km/h, 5.0-9.7 km/h, 9.8 km/h and greater (0-3.0 mph, 3.1-6.0 mph, 6.1 mph and greater) for each of the station comparisons (1 & 2, 1 & 3, and 2 & 3). The results of all of the tests showed no significant difference between the two groups, thus confirming that there was no difference between the two sets of data obtained by the two methods of data reduction.

Analysis

Computation of Vehicle Speeds

The first major step in the analysis stage of the project involved transforming the travel time data obtained from the videotapes into coherent speed data. All of the travel times were loaded onto spreadsheets. For each site, there were four spreadsheets, one for each message. First, the speed data for each vehicle from station 1 (which was recorded from the radar detector) were input into the computer, then the corresponding speeds at stations 2 and 3 for each particular vehicle were calculated. Basically, this process entailed inputting the number of whole seconds and thirtieths of a second into two separate columns and programming the third column to automatically calculate the speed according to the following equation:

$$\frac{45.7m\ (150ft)}{x}\left(\frac{1mile}{1609.3m\ (5280ft)}\right)\left(\frac{3600s}{1hr}\right) = y \qquad (1)$$

where X = the travel time of the vehicle in seconds
Y = the speed of the vehicle in mph.

An example of a typical spreadsheet can be found in Table 2.

Table 2: Work Zone Speed Data at I-81 South Near Lexington (Rockbridge County): Posted Speed Limit 55 mph, Threshold Speed Limit 58 mph

Station 1	Station 2			Station 3		
SPEED (mph)	Whole Seconds	Thirtieths of a Second	SPEED (mph)	Whole Seconds	Thirtieths of a Second	SPEED (mph)
66	1	24	56.82	1	27	53.83
64	1	26	54.79	2	1	50.30
61	2	5	47.20	2	1	50.30
62	2	1	50.30	2	1	50.30
59	1	23	57.89	1	24	56.82
60	2	2	49.49	2	3	48.70
68	1	29	52.00	2	5	47.20
69	2	16	40.37	3	13	29.79

Calculation of Average and Percentile Speeds

Camera Data

Having computed all of the speeds at stations 2 and 3, a sort program within the spreadsheet package was used to rank the speeds in ascending order. Each of the three speed columns was sorted individually to calculate the 85th percentile speed of those vehicles exceeding the threshold speed. In addition, average speeds were also computed at each station for each message using all of the data.

The camera data were then divided in order to assess the effect of the messages on high-speeding drivers in particular. The speed data at station 1 were sorted into two categories: 95-103 km/h and ≥ 104 km/h (59-64 mph and ≥ 65 mph). The corresponding speeds at stations 2 and 3 for each vehicle were also sorted along with station 1. Average speeds for the two speed categories were then calculated at each station for each message, and the *t* test was used to evaluate the reduction in speeds of the vehicles between the stations, i.e., between stations 1 & 2 and 1 & 3. The main purpose for this division was to observe the behavior of the two different groups of speeding vehicles as they traveled through the work zone.

Traffic Counters Data

The speed data for the periods when the cameras were not used at the work zone were obtained from the traffic counters. Three separate sets of data were extracted from the output. The first set represented the speeds of vehicles when only the standard MUTCD markings were in place, without the use of the CMS. The second and third sets were obtained for the times when the CMS was in place, but with and without the data collection team present.

First, the average and 85th percentile speeds were calculated at each station in order to observe the behavior of the whole population in response to the different conditions, i.e., either no CMS or one of the four messages on the CMS with and without the data collection team present. The effectiveness of the CMS was also scrutinized with respect to its effect on the speed variance. As a large speed variance has been shown to contribute to a greater number of accidents, it would be crucial to reduce this variability and bring more vehicles into the 10 mph pace.

The counters have the capability of categorizing speeds in a maximum of 12 bins. In order to obtain the widest range of possible speeds of vehicles in the work zone, the bins were programmed in increments of 3.2 km/h (2 mph), ranging from 74 to 109 km/h (46 to 68 mph). In other words, each of the 12 labeled bins contained the number of vehicles which were traveling at speeds higher than the speed of the bin preceding it up to the speed of that bin (Figure 8). For example, as the 74 km/h (46 mph) bin was the first bin, it contained the number of vehicles traveling 74 km/h (46 mph) and below. The 77.2 km/h (48 mph) bin contained the number of vehicles traveling above 74 km/h (46 mph) but not greater than 77.2 km/h (48 mph), and so on. As 109.4 km/h (68 mph) was the highest speed recorded, all vehicles traveling at speeds above 106.2 km/h (66 mph) were included in this bin. It should be noted that in extreme cases where traffic was observed to be slower or faster, slight variations in the range were made to accommodate the majority of the traffic traveling at that station. For example, at the work zone on I-64 East in Shadwell, it was observed that vehicles were entering the work zone at excessively high speeds; therefore, the bins at station 1 were programmed to range from 83.7 km/h (52 mph) to 119 km/h (74 mph).

The T240 program that downloads the counter data automatically calculates various speed characteristics, the mean speed and 85th percentile speed, for each interval. In this case, the interval was set to 60 minutes; therefore, hourly statistics were provided. These statistics were calculated within the program using the actual speeds detected by the counters; thus, these values accurately represent the speed characteristics of the whole population traveling through the work zone. This emphasizes the exactness of the calculations. If the averages and 85th percentile speeds had been calculated using the bin data only, the bin speed would have had to be used as the speed of all of the vehicles in that particular bin, thereby neglecting speeds lower and higher than each of the bin speeds and creating a discrepancy.

Tube Velocity Program with 24 Hour Totals

****

Data File : 08199301.TRF Position : 1
Station : 813 Ident : 1
Start Date : Aug 23 ,1992 End Date : Aug 24 ,1992
Start Time : 19:57 End Time : 20:00
Location : I 81 South Abingdon

****

Speed (from - to)

Begin	46	48	50	52	54	56	58	60	62	64	66	68	Total
20:00	11	27	19	50	62	71	64	39	45	23	21	16	448
21:00	11	9	6	45	43	50	57	32	39	28	15	16	351
22:00	10	13	25	43	33	49	39	29	41	26	9	14	331
23:00	12	16	17	32	36	32	20	17	18	3	3	4	210
00:00	11	11	11	32	31	23	20	13	15	10	4	9	190
01:00	3	9	9	22	23	20	17	13	12	13	2	6	149
02:00	2	6	10	19	16	20	19	17	14	11	5	7	146
03:00	4	11	12	14	27	24	26	19	9	5	4	3	158
04:00	2	12	16	25	25	31	27	11	17	7	4	10	187
05:00	2	14	18	28	41	45	45	31	26	7	9	10	276
06:00	6	38	35	78	53	56	60	46	40	19	8	19	458
07:00	5	40	42	82	91	99	88	65	66	40	26	21	665

****

Station Summary

Speed (from - to)

46	48	50	52	54	56	58	60	62	64	66	68	Total
79	206	220	470	481	520	482	332	342	192	110	135	3569

Total	Mean	15%ile	50%ile	85%ile	>55	%>55	>60	%>60	>65	%>65
3569	58.1	50.1	55.3	61.4	2113	59.2	779	21.8	245	6.9

****

Figure 8. Sample output from traffic counter.

The speed variances, on the other hand, had to be calculated using the bin speeds, since the program did not provide this statistic. As the bins held speeds in the range of 2 mph, that would imply only a small loss of accuracy. Therefore, the bin speeds were applicable in calculating speed variances to describe the overall data.

Significance Testing

The statistical techniques employed to test the significance of the speed reductions achieved with CMS included the odds ratio, analysis of variance (ANOVA), and the *t* test. The odds ratios were used to determine the odds of exceeding the speed limit in the work zone under the various conditions prescribed in the study; for example, the use of the four different messages on the CMS. The effectiveness of CMS was measured by the decrease in the odds for speeding when using CMS as compared to the odds for speeding when not using CMS. ANOVA was used with the whole population data to determine whether there were significant reductions in average and 85th percentile speeds, as well as speed variances, as a result of using the CMS. In addition, ANOVA was also used with the camera data to determine if there was a significant difference in speeds when using any of the four messages on the CMS. Finally, the *t* test was used with the camera data to test whether the high-speeding vehicles were significantly reducing their speeds as they traversed the three stations through the work zone.

Odds Ratio Calculations

The odds ratio (classical or frequentist cross product) is a statistical value which estimates the effect of a treatment by comparing conditions before and after its application.[41] In this case, the treatment was the use of CMS, or more specifically, the use of four preselected messages on CMS, to influence drivers to reduce speeds in the work zone. The effectiveness of CMS in achieving this goal was assessed by comparing the odds of exceeding the speed limit by any amount, by 8 km/h (5 mph) or more, and by 16.1 km/h (10 mph) or more when using CMS with the odds for speeding when using the standard MUTCD signing only.

The odds ratio estimate of treatment effectiveness is computed using the number of vehicles that were observed speeding and not speeding before and after the use of the treatment. Table 3 shows the format for categorizing the speed data.

The variables from Table 3 are applied in the following equation to compute the odds ratio:

$$OR = \frac{A/C}{B/D} = \frac{AD}{BC} \qquad (2)$$

Table 3: Tabular Format for Speed Data

	Treatment	Comparison[b]
Speeding [a]	A	B
Not Speed-ing	C	D

[a] Odds ratios for exceeding the speed limit by any amount, by 5 mph and by 10 mph were evaluated.
[b] Each of the four messages, with and without the data collection team present, was evaluated.

Note that A/C defines the odds for speeding after the treatment was applied, and B/D represents the odds for speeding before the use of the treatment. The ratio of the two numbers thus provides a means of determining whether a reduction in speeds was achieved through the use of the treatment. If the ratio is less than 1, then a reduction of x percent was achieved, where

$$x = (1 - OR)\,100 \qquad (3)$$

This reduction suggests that if CMS was applied on the same number of vehicles that were observed in the control condition, then an χ % reduction in the number of speeding vehicles in that group would be realized. A ratio greater than 1 would indicate that CMS did not reduce the number of speeding vehicles, but in fact, that there was an increase in the number of speeding vehicles compared to use of standard MUTCD signing only.

An example of this technique would be as follows: Let the treatment be the application of CMS without the data collection team present, using the message "YOU ARE SPEEDING SLOW DOWN." In particular, let the analysis be conducted to determine whether there was a significant reduction in the number of vehicles traveling at v mph above the speed limit, where $v \geq 0$ (i.e., speeding by any amount), after the treatment was applied at the work zone. Then the ratio of the number of vehicles traveling above the speed limit to the number of vehicles traveling at or below the speed limit before the use of the message would have to be compared with a similar ratio obtained after the use of the message.

For example, using equation 2 and the data shown in Table 4, the odds for the two conditions may be computed. The odds of exceeding the speed limit by any amount when using standard MUTCD signing only would be 165/238, or .69. The odds for speeding when using the CMS would be calculated as 102/364, or .28. The ratio of the two odds, .28/.69, produces a final odds ratio of .41. This odds ratio represents a 59% ((1-.41)100) reduction in the number of vehicles speeding when using the message "YOU ARE SPEEDING SLOW DOWN" on CMS.

Table 4: Speed Data for Odds Ratio Calculation

	"YOU ARE SPEEDING SLOW DOWN" [b]	MUTCD Signing Only
Speeding by ANY AMOUNT [a]	102	165
Not Speed-ing	364	238

[a] Odds ratios for exceeding the speed limit by any amount, by 5 mph and by 10 mph were evaluated.
[b] Each of the four messages, with and without the data collection team present, was evaluated.

The odds ratios for vehicles speeding by any amount, by 5 mph or more, and by 10 mph or more were computed in this manner for all of the messages at each site, as well as for each station within the work zone. In addition, the percentage reduction in speeding vehicles was also calculated and recorded with the final results.

Analysis of Variance

Camera Data

ANOVA was conducted with the speed data obtained from the videotapes in order to determine whether there were significant differences between the four messages with regards to average and 85th percentile speeds within the work zone. The comparison was made by testing the speeds at corresponding stations for each of the messages, i.e., when comparing two messages, the speeds at station 2 at all of the sites for one message were compared with the speeds at station 2 at all of the sites for the second message (and the same procedure was applied for station 3 speeds). The following null hypotheses were formulated for these tests:

[1] The average speeds at station 2 are the same for all four messages on the CMS.

[2] The 85th percentile speeds at station 2 are the same for all four messages on the CMS.

Whole Population Data

ANOVA was conducted using the speed data obtained from the traffic counters in order to determine whether the use of the CMS resulted in significant overall speed reductions through the differences in the speed data obtained when the data collection team was present at the work zone and the speed data obtained when it was not present at the work zone. The CMS and pneumatic tubes with traffic counters were present for both conditions, as the CMS was being evaluated and the tubes were needed to collect speed data. As these items were present for both cases, they were not considered a bias in favor of the CMS. However, the cameras, LED lights, and crew were removed from the site for the ''data collection team not present" condition. Thus, if there were no significant differences in the two sets of data, it would be reasonable to assume that the presence of the data collection team when recording the camera data also did not bias the results.

The tests compared the two conditions for average speeds, 85th percentile speeds, and speed variances at stations 2 and 3 using the whole population data. The following set of null hypotheses were developed (these were repeated for station 3 speeds and for each of the other two speed characteristics, 85th percentile speeds and speed variance):

[3] The average speeds at station 2 with the data collection team present are the same as the average speeds without the data collection team present for the message ''EXCESSIVE SPEED SLOW DOWN".

[4] The average speeds at station 2 with the data collection team present are the same as the average speeds without the data collection team present for the message ''HIGH SPEED SLOW DOWN".

[5] The average speeds at station 2 with the data collection team present are the same as the average speeds without the data collection team present for the message ''REDUCE SPEED IN WORK ZONE".

[6] The average speeds at station 2 with the data collection team present are the same as the average speeds without the data collection team present for the message ''YOU ARE SPEEDING SLOW DOWN".

The whole population data obtained from the automatic counters were also used to evaluate the effect of CMS on three particular characteristics of the speed profiles through the work zone: average speeds, 85th percentile speeds, and speed variances. Its effectiveness was determined by comparing each speed characteristic at station 2 when using CMS with the corresponding speed characteristic at station 2 when not using CMS. This procedure was repeated for station 3. In addition, the four messages were tested against one another to determine whether any of the messages were more effective in reducing vehicle speeds. Significance tests were also conducted to evaluate the change in the percentage of vehicles speeding by any amount, by 8 km/h (5 mph) or more, and by 16 km/h (10 mph) or more at each of the three stations within the work zone as a result of using each of the four messages on the CMS.

The five null hypotheses stated below pertain to the average speeds that were calculated at station 2. It should be noted that the 85th percentile speeds, the speed variances, and the percentages of vehicles in each category were all tested in a similar manner. In addition, all of the speed characteristics were evaluated at station 3 as well.

[7] The average speeds at station 2 using the CMS displaying the message ''EXCESSIVE SPEED SLOW DOWN" are the same as when using standard MUTCD signing only.

[8] The average speeds at station 2 using the CMS displaying the message ''HIGH SPEED SLOW DOWN" are the same as when using standard MUTCD signing only.

[9] The average speeds at station 2 using the CMS displaying the message ''REDUCE SPEED IN WORK ZONE" are the same as when using standard MUTCD signing only.

[10] The average speeds at station 2 using the CMS displaying the message ''YOU ARE SPEEDING SLOW DOWN" are the same as when using standard MUTCD signing only.

[11] The average speeds at station 2 are the same when displaying any one of the four messages on the CMS.

t Test

The speed data obtained from the videotapes were analyzed separately using the *t* test in order to examine the effect of the CMS on high-speeding vehicles in particular. The averages determined using the data separated into two speed categories, where station 1 speeds were divided into groups having speeds 94.9- 103 km/h and ≥ 104.6 km/h (59-64 mph and ≥ 65 mph), were analyzed using the *t* test in order to determine whether there was a significant reduction in vehicle speeds between stations 1 and 2 and 1 and 3. The following null hypotheses, applicable to both speed categories, were developed for these tests:

[12] The average speeds at stations 2 and 3 are the same as the average speeds at station 1 when using the message ''EXCESSIVE SPEED SLOW DOWN" on the CMS.

[13] The average speeds at stations 2 and 3 are the same as the average speeds at station 1 when using the message ''HIGH SPEED SLOW DOWN" on the CMS.

[14] The average speeds at stations 2 and 3 are the same as the average speeds at station 1 when using the message ''REDUCE SPEED IN WORK ZONE" on the CMS.

[15] The average speeds at stations 2 and 3 are the same as the average speeds at station 1 when using the message ''YOU ARE SPEEDING SLOW DOWN" on the CMS.

RESULTS

The traffic counter data and the camera data in the form of spreadsheets will not be provided in the report in their actual form due to the enormous size of these data bases. However, the various statistics of the speed profiles that were calculated using this data are in the appendices at the end of the report. All of these statistics are provided for each site at each of the three stations under all of the treatment conditions, i.e., no CMS and each of the four messages, with and without the data collection team present.[1]

1. It should be noted that at the last two sites (I-81 South in Abingdon and I-64 East in Shadwell), a fifth message, "SLOW DOWN NOW", was also tested. There was not enough data to conduct significance tests using this message, but inspection of the statistics calculated for the two sites indicates that this message may also have some speed-reducing benefits.

Appendix D contains the statistics for the camera data, which includes the average speeds and 85th percentile speeds in Tables D-1 and D-2, respectively. Table D-3 provides the average speeds determined at each station when station 1 speeds were divided into two categories: 94.9 - 103 km/h and ≥ 103 km/h (59-64 mph and ≥ 65 mph).

Figures 9 and 10 show the average and 85th percentile speeds calculated for high-speed vehicles (using the camera data) at the work zone on I-81 South at Buffalo Gap. This site was chosen to illustrate some of the trends that were observed at nearly all of the sites. The graphs in figure 9 show that vehicle speeds were reduced at stations 2 and 3 for all of the messages used on CMS. In addition, the messages "HIGH SPEED SLOW DOWN" and "YOU ARE SPEEDING SLOW DOWN" appear to have had a greater impact on vehicle speeds than the other two messages. Figure 10, which illustrates the 85th percentile speeds at this site, confirms this finding.

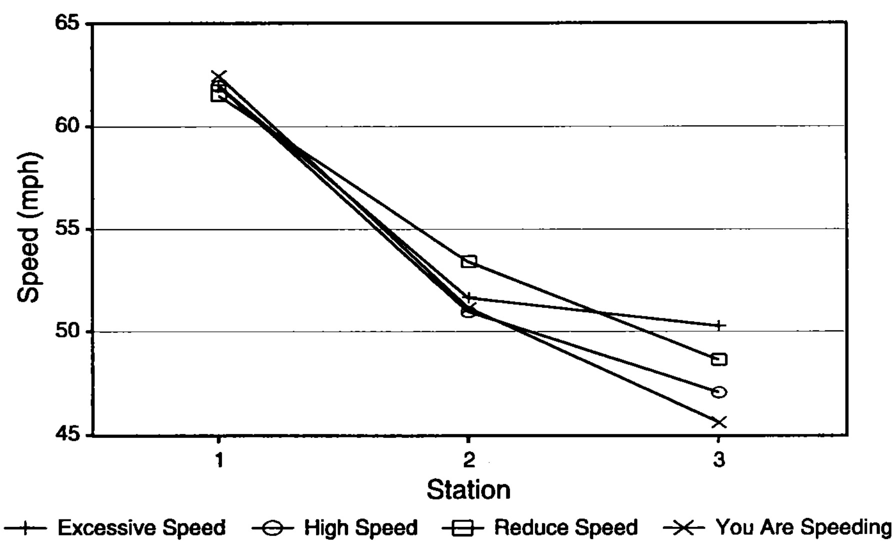

Figure 9. Average speeds (mph) -- camera data (I-81 South Buffalo Gap).
Threshold speed limit 58 mph; posted speed limit 55 mph.

As shown in the figure, the 85th percentile speeds decreased for all of the messages; but the two messages mentioned above were more effective, reducing these speeds to values at or below the posted speed limit.

A particular trend observed at one site shows more clearly the difference in effectiveness of the four messages in bringing vehicle speeds closer to the speed limit. In Figure 11, the 85th percentile speeds at I-64 East in Shadwell for the messages "HIGH SPEED SLOW DOWN" and "YOU ARE SPEEDING SLOW DOWN" became consistently lower. However, this graph also shows that the speeds increased again between stations 2 and 3 for the messages "EXCESSIVE SPEED SLOW DOWN" and "REDUCE SPEED IN WORK ZONE". Using the latter two messages, there is a reduction in 85th percentile speeds by approximately 4.8-6.4 km/h (3-4 mph) between stations 1 and 2; however, by the time vehicles reach station 3, there is a slight increase in 85th percentile speeds. This may indicate that these two particular messages did not have a lasting impact on drivers as they progressed through the work zone. The average speeds for these two messages also exhibited this tendency, although to a slightly lesser degree.

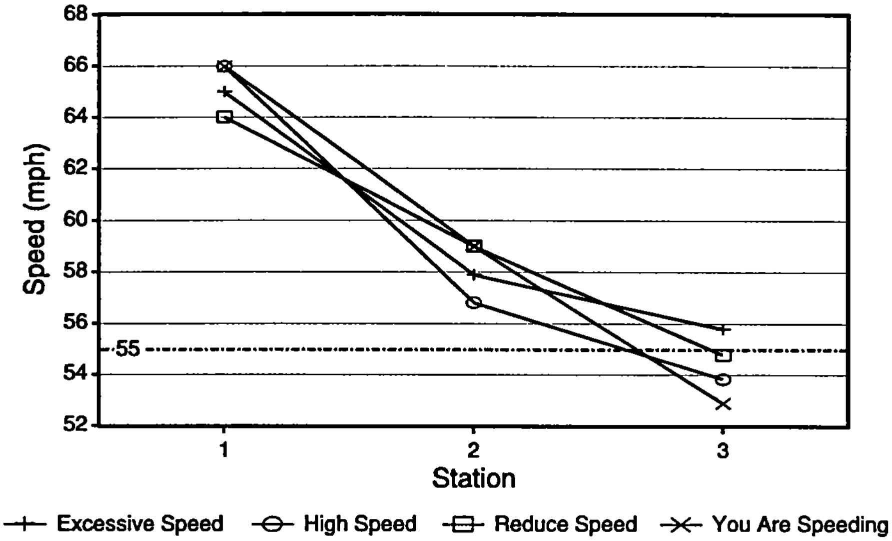

Figure 10. 85th percentile speeds (mph) -- camera data (I-81 South Buffalo Gap).
Threshold speed limit 58 mph; posted speed limit 55 mph.

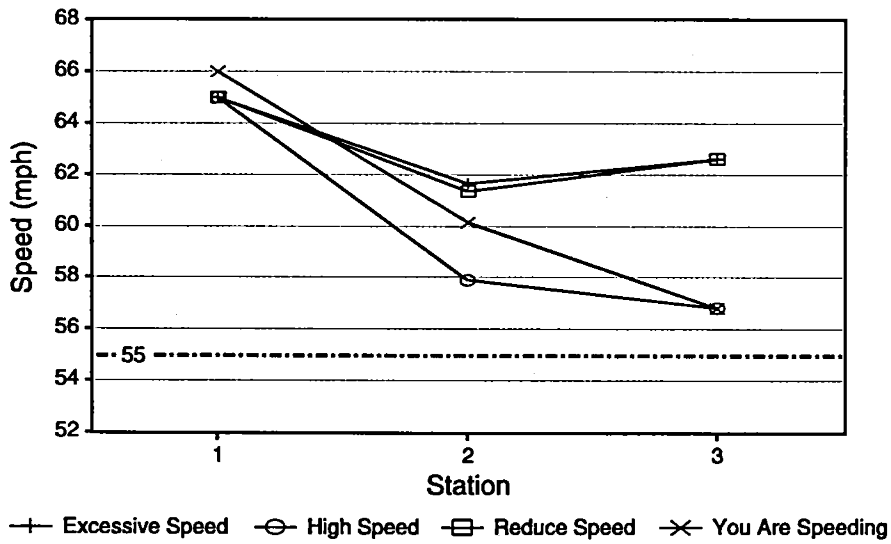

Figure 11. 85th percentile speeds (mph) -- camera data (I-64 East Shadwell).
Threshold speed limit 58 mph; posted speed limit 55 mph.

Table D-3, which contains the average speeds at each station based on the two speed categories at station 1, 94.9-103 km/h and ≥ 104.6 km/h (59-64 mph and ≥65 mph), shows the benefits of using CMS with regard to reducing speed variance. The notable trend in this table can best be described with an example: For the speeds at I-81 South at Buffalo Gap for the message "EXCESSIVE SPEED SLOW DOWN", the difference in average speeds at station 1 for the two speed categories was approximately 9 km/h (5.6 mph, i.e 66.6 mph - 61.0 mph). By station 2, this difference reduced to approximately 5.4 km/h (3.4 mph, i.e. 54.3 mph - 50.9 mph). Finally, by station 3, the difference in average speeds for the two high-speeding groups dropped to 1.1 km/h (0.7 mph, i.e.50.8 mph - 50.1 mph). The average speeds for all of the messages at all of the sites showed this similar trend in driver behavior, although to slightly different degrees. The fact that all of the high-speed vehicles tend to converge to a similar speed by the time they reach station 3 suggests that CMS could have a positive impact on reducing speed variance.

Appendix E contains the statistics for the whole population data, as obtained from the traffic counters. In addition to average speeds and 85th percentile speeds (shown in Tables E-1 and E-2, respectively), speed variances and the percentage of vehicles speeding by any amount, by 8 km/h (5 mph) or more, and by 16 km/h (10 mph) or more were also calculated and are shown in Tables E-3, E-4, E-5, and E-6, respectively.

As shown in Figures 12 and 13, the average and 85th percentile speeds of the whole population were noticeably reduced with the use of CMS on I-64 East in Short Pump. All of the sites exhibited this trend. While there are slight deviations in the speed reductions among the four messages, there appears to be no indication that one message might be more effective than another at this particular site.

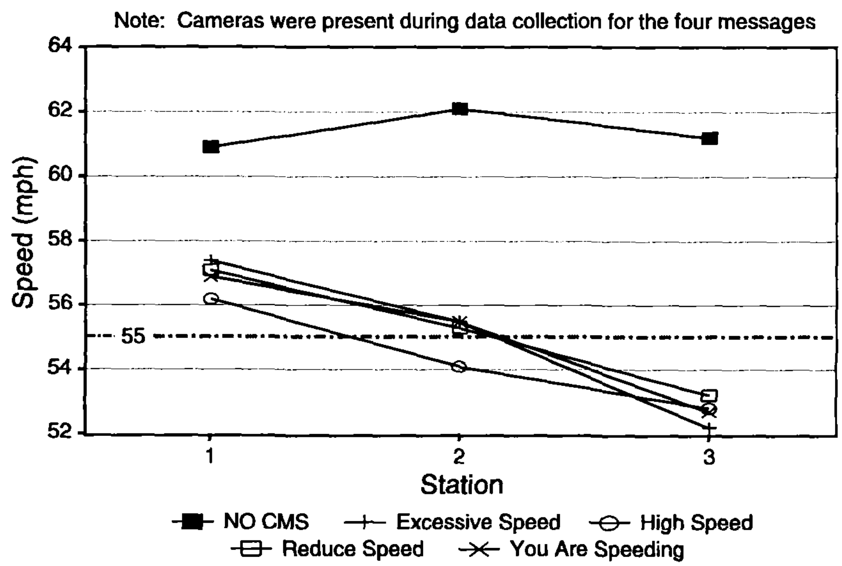

Figure 12. Average speeds (mph) -- whole population data (I-64 East Short Pump).
Threshold speed limit 58 mph; posted speed limit 55 mph.

This observation is verified by Figures 14, 15 and 16, which show the percentage of vehicles speeding by any amount, by 5 mph or more, and by 10 mph or more. All of the messages reduced the percentage of vehicles speeding through the work zone. Figure 15 in particular demonstrates that CMS had an effect on high-speed vehicles (average speeds tend to disguise this important factor). Although there was a slight rise in the percent of drivers speeding by 16 km/h (10 mph) or more between stations 1 and 2 for two of the messages as shown in Figure 16, the percentage of vehicles traveling above 16 km/h (10 mph) over the speed limit was still reduced notably when compared with that for the NO CMS condition. Unfortunately, there was some problem with the traffic counter at station 3 which resulted in speeds not being recorded for those two messages at this site. Trends observed from the data at the other sites have indicated that speeds usually do decrease again by the time vehicles approach station 3.

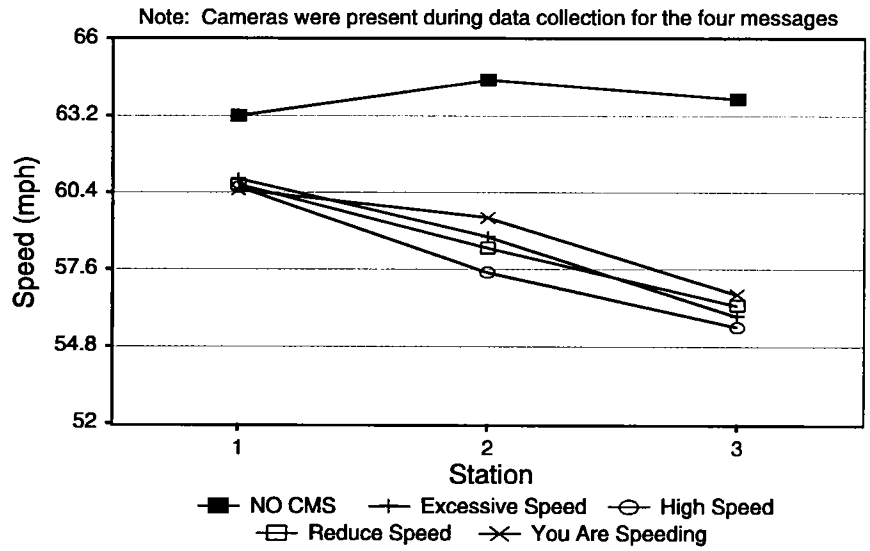

Figure 13. 85th percentile speeds (mph) -- whole population data (I-64 East Short Pump).
Threshold speed limit 58 mph; posted speed limit 55 mph.

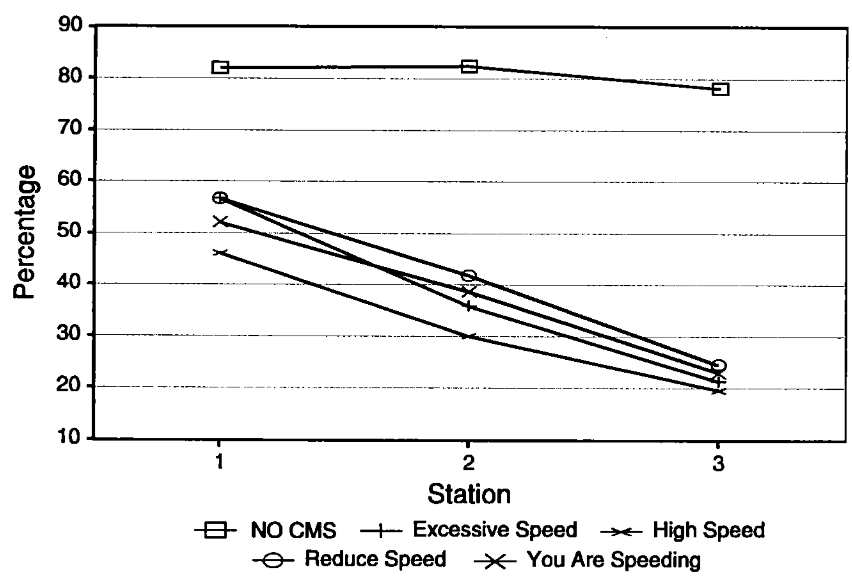

Figure 14. Percent speeding by any amount -- whole population data (I-64 East Short Pump).
Threshold speed limit 58 mph; posted speed limit 55 mph.

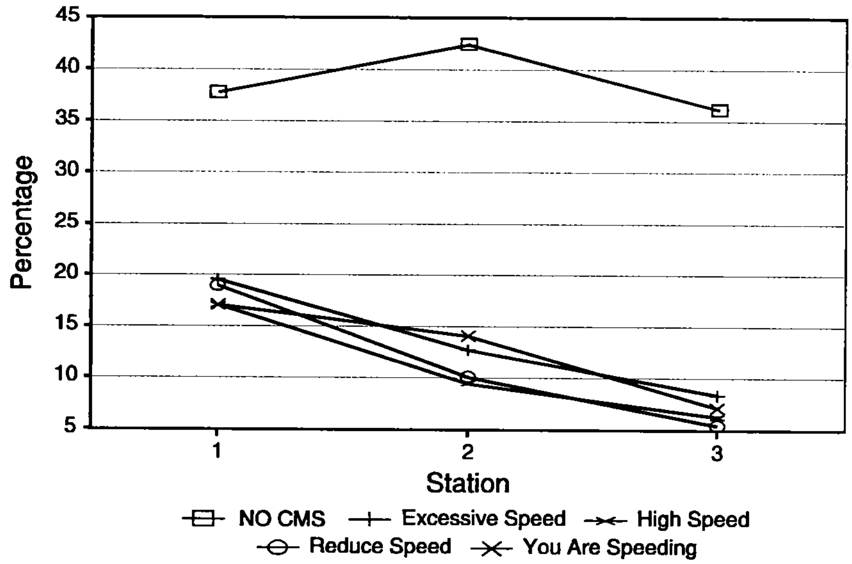

Figure 15. Percent speeding by 5 mph or more -- whole population data (1-64 East Short Pump
Threshold speed limit 58 mph; posted speed limit 55 mph.

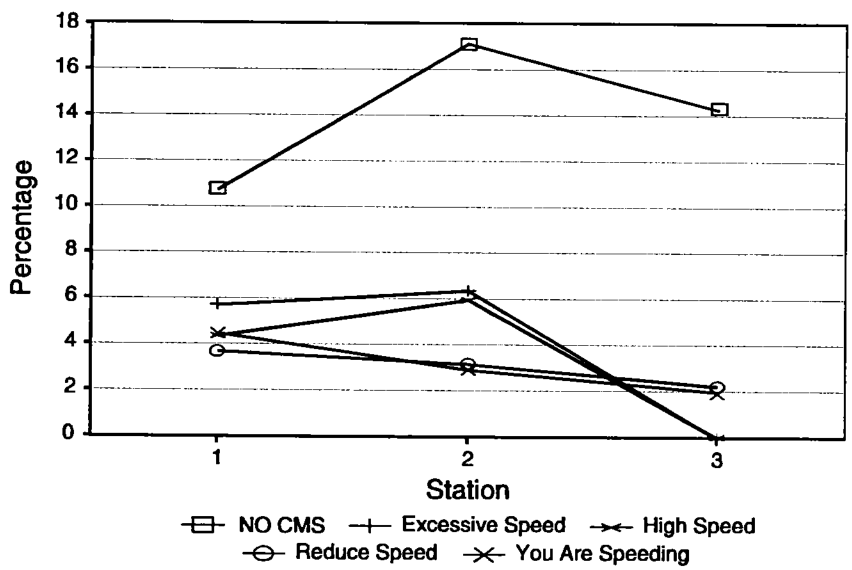

Figure 16. Percent speeding by 10 mph or more -- whole population data (I-64 East Short Pum
Threshold speed limit 58 mph; posted speed limit 55 mph.

Table 5. Summary of Significance Tests

ID Number	Purpose	Statistical Technique	Comparison	Hypothesis Number	Type of Data	Data Tables	Table of Results
1	To assess the effectiveness of the CMS by comparing the odds for speeding when using the CMS and when not using the CMS	Odds Ratio	Odds for speeding when using each of the messages vs odds for speeding when using MUTCD signing only	—	*Whole Population Data*	Traffic Counters Data	Tables F-1 through F-7 (Appendix F)
2	To determine if there was a significant difference in speeds when using any one of the 4 messages on the CMS	ANOVA	4 messages against one another	1 & 2	*Camera Data* Average and 85th Percentile Speeds	Tables D-1 and D-2 (Appendix D)	Table 6
3	To determine if there were significant differences in the data obtained when the data collection team was present and not present at the work zone	ANOVA	Speed data with data collection team present vs speed data without the data collection team present	3 - 6	*Whole Population Data* Average and 85th Percentile Speeds, Speed Variance	Tables E-1, E-2, and E-3 (Appendix E)	Table 7
4	To assess the effect of each message on speeds as compared to speeds when using MUTCD signing only	ANOVA	No CMS vs each message	7 - 10	*Whole Population Data* Average and 85th Percentile Speeds, Speed Variance, Percentages of Vehicles Speeding	Tables E-1 through E-6 (Appendix E)	Table 8 & Tables 10 through 14
5	To determine if there was a significant difference in speeds when using any one of the 4 messages on the CMS	ANOVA	4 messages against one another	11	*Whole Population Data* Average and 85th Percentile Speeds, Speed Variance, Percentage of Vehicles Speeding	Tables E-1 through E-6 (Appendix E)	Table 9
6	To determine if the high-speeding vehicles were reducing vehicles speeds through the work zone	*t* Test	Station 1 vs Station 2 Station 1 vs Station 3 (where Station 1 was divided into two categories: 59-64 mph and $\geq$ 65 mph)	16 - 19	*Camera Data* Average Speeds (when Station 1 speeds were broken into two speed categories)	Table D-3 (Appendix D)	Tables 16 & 17

Summary of Significance Testing

An inventory of the various statistical tests conducted during the course of the analysis are in Table 5. This table summarizes the purpose of each of the tests and supplies information regarding the statistical technique employed to conduct the test, the data used for the tests, and the tables where the results of each test may be found. This catalog is a quick reference to aid in distinguishing between the many different tests; each will be referred to in the text by the identification number provided in the first column of the table.

Summary of the Odds Ratios Calculations

The odds ratios calculated for each site using the whole population data can be found in Appendix F, Tables F-1 through F-7 (see ID #1, Table 5). The ratios were determined at each station for each message, with and without cameras present, for three separate categories: speeding by any amount, by 5 mph or more, and by 10 mph or more. In addition, the expected percentage reduction in the number of speeding vehicles that would have been observed in the MUTCD-only condition if CMS was used, is shown in parentheses next to each odds ratio.

It should be noted that in each of the tables, the first row contains data on the odds for speeding with no CMS. This value is the ratio of the number of vehicles speeding to the number of vehicles not exceeding the speed limit when CMS was not in place. This value was used to calculate the odds ratios for the applications of the various treatments; i.e., the B/D (see Table 3) that was used on the bottom of the odds ratio.

This terminology implies that the odds ratios are related vertically, not horizontally, in the table. For example, in Table F-2 (I-64 East Covington), the odds for speeding by any amount with no CMS at station 1 is 1.03. This value, which signifies that the odds for speeding with no CMS are over 100%, was used on the bottom of the odds ratio computation for all of the messages at station 1 for vehicles speeding by any amount. For the message "EXCESSIVE SPEED SLOW DOWN", the odds ratio of .17 suggests that if the vehicles used in the control condition were reevaluated using CMS, there would be an 83% reduction in the number of vehicles speeding. Using the same logic, the odds for speeding by 5 mph or more with no CMS are .36 at station 1. The odds ratio for "EXCESSIVE SPEED SLOW DOWN" for this speed category are .11, which suggests that an 89% reduction in the number of vehicles speeding by 5 mph or more would be achieved in the control group when this message was used on CMS.

The odds ratios thus calculated indicate that CMS was effective in reducing the number of vehicles speeding at all three of the stations for all of the messages at all of the sites.[1] The percentage reduction in the number of vehicles speeding in all three of the speed categories shows that all vehicles, as well as high-speed vehicles, reduced their speed as a result of CMS. For example, approximately three-fourths of the odds ratios that were calculated represent a potential reduction of 70% or greater in the number of vehicles speeding if CMS was used in the work zone.

1. The odds ratio for the message "REDUCE SPEED IN WORK ZONE" (when the data collection team was not present) at station 2, I-81 South in Abingdon, was the only odds ratio greater than 1.

These odds ratios reemphasize the information provided in Tables E- 4, E-5, and E-6 in Appendix E, which provide the percentages of vehicles speeding by any amount, by 8 km/h (5 mph) or more, and by 16 km/h (10 mph) or more, respectively. As evidenced in these three tables, CMS has a noticeable effect on the number of vehicles speeding in the whole population.

ANOVA Results

Before these results are presented, it should be noted that the data for the work zone at I-81 North in Abingdon could not be used in the analysis. While the original intent of this project was to test CMS in various different environments, that is, types of highway, different speed reductions, etc., the lack of diversity among the sites did not permit the realization of this objective. The site at I-81 North in Abingdon was the only work zone where the normal speed limit of 104.6 km/h (65 mph) was reduced to 72.4 km/h (45 mph), and this data could not be compared with the data for the remaining sites as they were all reduced from 104.6 km/h to 88.5 km/h (65 mph to 55 mph).

From visual observation, however, the data at this site appear to show the same trends (see Tables D-1, D-2, and D-3); in other words, speeds did reduce with the use of CMS. Noteworthy, however, are the higher speed differences between the actual driving speeds and the posted speed limit of 72.4 km/h (45 mph). While drivers did reduce their speed, the large speed difference suggests that they were less apt to reduce speeds to the speed limit. For example, the 85th percentile speeds derived using the camera data (Table D-2 in Appendix D) indicate that as they entered the work zone, the high-speed vehicles were up to 32.2 km/h (20 mph) over the speed limit. At the 72.4 km/h (55 mph) work zones, however, drivers with the highest speeds were generally traveling at about 16 km/h (10 mph) above the speed limit. From the whole population data, the percentages of vehicles speeding by any amount, by 8 km/h (5 mph) or more, and by 16 km/h (10 mph) or more (Tables E-4, E-5, and E-6 in Appendix E) clearly illustrate the immense difference in the acceptance levels of the two different reduced speed limits. The percentages for the 72.4 km/h (45 mph) work zone were much higher than those for the remaining six sites. The results tend to suggest that drivers may not have felt the need to reduce speeds by 32.2 km/h (20 mph).

CMS appears to have been as effective at this site as it was at the others, as noted by the speed reductions and the similar trends in the data. It was unfortunate that there were no other sites to compare the data with in order to determine how a 32.2 km/h (20 mph) speed reduction would be accepted elsewhere. This site, however, does indicate the behavior of the driving public under a different condition, and the importance of having a justifiable speed reduction.

Camera Data

In the first set of tests, ANOVA was used with the camera data in order to determine if there was a significant difference in speeds when using any of the four messages on the CMS (ID #2, Table 5). The average and 85th percentile speeds at stations 2 and 3 were tested, and there was no significant difference between any of the messages with regard to these statistics. Table 6 shows the results obtained from the tests conducted using the average speeds at stations 2 and 3. The results from the 85th percentile speed tests are not shown here due to redundancy in output (as no differences were significant); however, this table is provided as a representative example.

Based on the results of all of the tests, which indicated no significant difference at $\alpha = .05$ among the average and 85th percentile speeds for the 4 different messages, null hypotheses 1 and 2 were not rejected for both station 2 and station 3 speed comparisons.

Table 6: Results of ANOVA -- Average Speeds Using Camera Data. Comparison of the 4 Messages.

1st Message	2nd Message	Station 2		Station 3	
		F	Significance of *F*	*F*	Significance of *F*
EXCESSIVE SPEED SLOW DOWN vs	HIGH SPEED	.002	.967	.695	.422
	REDUCE SPEED	.220	.649	.020	.891
	YOU ARE SPEEDING	.066	.803	1.230	.291
HIGH SPEED SLOW DOWN vs	REDUCE SPEED	.234	.639	.534	.479
	YOU ARE SPEEDING	.110	.747	.047	.833
REDUCE SPEED IN WORK ZONE vs	YOU ARE SPEEDING	.526	.485	1.006	.336

Whole Population Data

In the first set of tests, ANOVA was used to determine whether there were significant differences in the data obtained when the data collection team was present and not present at the work zone (ID #3, Table 5). At a significance level of $\alpha = .05$, there was no difference in the average speeds, 85th percentile speeds, and speed variances at either station 2 or 3 under the two different conditions. In light of these results, the presence of the data collection team will not be considered a bias in favor of CMS when judging its effectiveness. Null hypotheses 3 through 6 were therefore not rejected for each of the speed characteristics at both stations 2 and 3. An example of the output can be seen in Table 7, which shows the results for the tests which compared average speeds for the two different conditions.

The results of the ANOVA conducted to assess the effect of each message on speeds as compared to speeds when not using CMS can be found in Table 8 and Tables 10 through 14 (ID #4, Table 5). The results shown in Table 8, for average speeds, indicate that the messages "YOU ARE SPEEDING SLOW DOWN" and "HIGH SPEED SLOW DOWN" are the most effective of the four messages. They both show a significant reduction in average speeds at stations 2 and 3 with the use of CMS. Null hypotheses 8 and 10 were therefore rejected for average speeds at both stations 2 and 3.

Table 7: Results of ANOVA -- Average Speeds Using Whole Population Data. Data Collection Team Present vs Data Collection Team Not Present

Condition	Station 2		Station 3	
	F	Significance of *F*	*F*	Significance of *F*
EXCESSIVE SPEED SLOW DOWN	.252	.634	.758	.406
HIGH SPEED SLOW DOWN	.003	.960	.319	.586
REDUCE SPEED IN WORK ZONE	.656	.441	.410	.540
YOU ARE SPEEDING SLOW DOWN	.130	.727	.093	.769

Table 8: Results of ANOVA -- Average Speeds Using Whole Population Data. No CMS vs Each of the 4 Messages

Condition	Station 2		Station 3	
	F	Significance of *F*	*F*	Significance of *F*
No CMS vs EXCESSIVE SPEED SLOW DOWN	3.826	.086	6.192	.032[a]
No CMS vs HIGH SPEED SLOW DOWN	8.294	.018[a]	8.165	.017[a]
No CMS vs REDUCE SPEED IN WORK ZONE	7.098	.024[a]	4.384	.063
No CMS vs YOU ARE SPEED-ING SLOW DOWN	9.605	.011[a]	8.735	.014[a]

[a] Significance at 5% significance level.

Each of the remaining two messages had significant differences at one station only. For the message "EXCESSIVE SPEED SLOW DOWN" there was a significant difference in average speeds at station 3 while for "REDUCE SPEED IN WORK ZONE" the difference was at station 2. These results might indicate that drivers are not responding to the messages in a consistent manner. In other words, the messages may not be as influential or forceful as the first two messages or make as strong an impression on all drivers as desired. For example, in using the message "REDUCE SPEED IN WORK ZONE" there is a significant reduction in average speeds between station 1 and 2, but speeds rise again before the end of the work zone. This suggests that the message may not have had a lasting impression on drivers. Based on these results, null hypothesis 7 for average speeds was only rejected at station 3 and null hypothesis 9 for average speeds was only rejected at station 2.

In tests conducted comparing all four of the messages, none of the results showed any significant difference in average speeds, 85th percentile speeds, speed variance, or any of the percentages at stations 2 or 3 (ID #5, Table 5). These results confirm the trends observed in Figures 12 through 15, which graphically showed only slight differences among the four messages. Thus, null hypothesis 11 was not rejected for any of the speed characteristics. Table 9 shows the results of the tests conducted using the average speeds at stations 2 and 3. Due to the large magnitude of output, which would be redundant as none of the results showed significant differences, only this table is provided as an example.

Table 9: Results of ANOVA -- Average Speeds Using Whole Population Data. Comparison of the 4 Messages.

1st Message	2nd Message	Station 2		Station 3	
		F	Significance of *F*	*F*	Significance of *F*
EXCESSIVE SPEED SLOW DOWN vs	HIGH SPEED	.392	.551	.004	.949
	REDUCE SPEED	.082	.782	.170	.689
	YOU ARE SPEEDING	.600	.461	.016	.903
HIGH SPEED SLOW DOWN vs	REDUCE SPEED	.163	.696	.299	.597
	YOU ARE SPEEDING	.043	.840	.006	.942
REDUCE SPEED IN WORK ZONE vs	YOU ARE SPEEDING	.359	.562	.379	.552

The results in Table 10 show that all of the messages are effective in reducing the 85th percentile speeds of vehicles traveling through the work zone. When compared with the 85th percentile speeds for the control condition without CMS, all of the differences were found to be significant at α = .05. Thus, null hypotheses 7 through 10 were rejected for 85th percentile speeds[a]

For comparisons of speed variance between no CMS and the four messages, "EXCESSIVE SPEED SLOW DOWN" was the only message that did not have significant differences in variance at stations 2 or 3. Thus, null hypothesis 7 was not rejected for speed variance at both stations. When all of the results thus far are considered together, it appears that this message may be the least effective of the group. As shown in Table 11, the remaining three messages were effective in significantly reducing speed variance when compared to conditions when CMS was not in use. Thus, null hypotheses 8 through 10 were rejected for speed variance at both stations 2 and 3.

Table 10: Results of ANOVA -- 85th Percentile Speeds Using Whole Population Data. No CMS vs Each of the 4 Messages

Condition	Station 2		Station 3	
	F	Significance of F	F	Significance of F
No CMS vs EXCESSIVE SPEED SLOW DOWN	6.194	.038[a]	9.363	.012[a]
No CMS vs HIGH SPEED SLOW DOWN	11.970	.007[a]	14.303	.004[a]
No CMS vs REDUCE SPEED IN WORK ZONE	9.616	.011[a]	7.091	.024[a]
No CMS vs YOU ARE SPEED-ING SLOW DOWN	13.203	.005[a]	18.355	.002[a]

[a] Significance at 5% significance level.

Table 11: Results of ANOVA -- Speed Variances Using Whole Population Data. No CMS vs Each of the 4 Messages

Condition	Station 2		Station 3	
	F	Significance of F	F	Significance of F
No CMS vs EXCESSIVE SPEED SLOW DOWN	1.675	.232	4.738	.055
No CMS vs HIGH SPEED SLOW DOWN	6.763	.029[a]	8.049	.018[a]
No CMS vs REDUCE SPEED IN WORK ZONE	7.195	.023[a]	9.512	.012[a]
No CMS vs YOU ARE SPEED-ING SLOW DOWN	6.746	.027[a]	14.722	.003[a]

[a] Significance at 5% significance level.

Tables 12, 13, and 14 show the results for the comparisons of the percentage of vehicles speeding according to the three speeding categories. The results for speeding by any amount confirm the trends illustrated in the earlier results. All of the messages were effective in reducing the total number of speeding vehicles. The significance of *F* for "REDUCE SPEED IN WORK ZONE" is .051 at station 3; however, this value is still very close to $\alpha = .05$. The fact that this message was not as effective at the end of the work zone once again indicates that it may not have had a lasting effect on drivers. Null hypotheses 7 through 10 were therefore rejected for the percentage of vehicles speeding by any amount at both stations 2 and 3.

Table 12: Results of ANOVA -- Percentage Speeding by Any Amount. No CMS vs Each of the 4 Messages

Condition	Station 2		Station 3	
	F	Significance of F	F	Significance of F
No CMS vs EXCESSIVE SPEED SLOW DOWN	5.931	.041[a]	6.492	.029[a]
No CMS vs HIGH SPEED SLOW DOWN	10.229	.011[a]	11.811	.006[a]
No CMS vs REDUCE SPEED IN WORK ZONE	8.402	.016[a]	4.937	.051[a]
No CMS vs YOU ARE SPEEDING SLOW DOWN	12.102	.006[a]	13.253	.005[a]

[a] Significance at 5% significance level.

Table 13: Results of ANOVA -- Percentage Speeding by 5 MPH or More. No CMS vs Each of the 4 Messages

Condition	Station 2		Station 3	
	F	Significance of F	F	Significance of F
No CMS vs EXCESSIVE SPEED SLOW DOWN	2.896	.127	4.271	.066
No CMS vs HIGH SPEED SLOW DOWN	4.558	.062	5.688	.038[a]
No CMS vs REDUCE SPEED IN WORK ZONE	6.085	.033[a]	3.657	.085
No CMS vs YOU ARE SPEEDING SLOW DOWN	5.495	.041[a]	7.213	.023[a]

[a] Significance at 5% significance level.

Table 13 shows that for vehicles speeding by 8 km/h (5 mph) or more, ''YOU ARE SPEEDING SLOW DOWN" was the only message that brought about a significant reduction in the number of vehicles speeding at this level at both stations 2 and 3. ''EXCESSIVE SPEED SLOW DOWN" did not significantly reduce the number of vehicles speeding by 8 km/h (5 mph) or more at either station, and the remaining two messages both reduced the percentages at only one station each. Thus, for the percentage of vehicles speeding by 8 km/h (5 mph) or more, null hypothesis 7 was not rejected, null hypothesis 8 was rejected at station 3 only, null hypothesis 9 was rejected at station 2 only, and null hypothesis 10 was rejected at both stations 2 and 3.

Table 14: Results of ANOVA -- Percentage Speeding by 10 MPH or More. No CMS vs Each of the 4 Messages

Condition	Station 2		Station 3	
	F	Significance of F	F	Significance of F
No CMS vs EXCESSIVE SPEED SLOW DOWN	1.411	.269	2.958	.120
No CMS vs HIGH SPEED SLOW DOWN	2.913	.122	3.787	.080
No CMS vs REDUCE SPEED IN WORK ZONE	3.578	.088	2.744	.129
No CMS vs YOU ARE SPEEDING SLOW DOWN	2.790	.126	4.398	.065

[a] Significance at 5% significance level.

Finally, for the percentage of vehicles speeding by 16 km/h (10 mph) or more, none of the results showed significant differences between the messages and no CMS at station 2 or 3 when using the whole population data (Table 13). Null hypotheses 7 through 10 were therefore not rejected for vehicles speeding by 16 km/h (10 mph) or more. It was considered that the drivers traveling at speeds this high over the threshold speed may not have been able to read and react to the messages. However, the data collection team experimented with the sign and confirmed that the messages were legible at high approaching speeds.

Despite the fact that these differences were not significant, the messages did succeed in reducing the number of vehicles speeding by 16 km/h (10 mph) or more. The results in Table E-6 in Appendix E confirm this observation. The analysis using the *t* test, conducted using the camera data, also serves to support this claim. The reduction in the number of speeding vehicles may not have been significant because the actual number of vehicles traveling at this speed level was so low for all of the conditions. In statistical testing, the ability to prove significant differences is lessened when working with small sample sizes.

Results of the *t* Tests

The camera data were divided into two separate categories according to vehicle speeds at station 1 as they entered the work zone (ID #6, Table 5). The first category was the 59-64 mph speed group. When the average speeds of vehicles at station 1 for this group were compared to the average speeds of these same vehicles at stations 2 and 3, it was found that there was a significant reduction in average speeds at both stations. The results of these *t* tests can be found in Table 15.

Table 15: Results of *t* Tests -- 59-64 MPH Speed Group. Station 1 to Stations 2 and 3

Message	Station 1 to Station 2		Station 1 to Station 3	
	t	Significance of *t*	*t*	Significance of *t*
EXCESSIVE SPEED SLOW DOWN	4.430073	.0114[a]	5.434806	.0029[a]
HIGH SPEED SLOW DOWN	7.681122	.0015[a]	8.951506	.0003[a]
REDUCE SPEED IN WORK ZONE	4.896015	.0081[a]	6.006936	.0018[a]
YOU ARE SPEEDING SLOW DOWN	6.823475	.0024[a]	7.908467	.0005[a]

[a] Significance at 5% significance level.

The *t* tests were also conducted for the second speed group, ≥ 65 mph, and the same results were obtained, as shown in Table 16. For all of the messages, the average speeds at stations 2 and 3 were reduced when compared to the average speeds of this high-speed group of vehicles at station 1. Thus, null hypotheses 12 through 15 were rejected for both speed groups when comparing station 1 to station 2 as well as station 1 to station 3.

Table 16: Results of *t* Tests -- ≥ 65 MPH Speed Group. Station 1 to Stations 2 and 3

Message	Station 1 to Station 2		Station 1 to Station 3	
	t	Significance of *t*	*t*	Significance of *t*
EXCESSIVE SPEED SLOW DOWN	6.01335	.0039[a]	7.494053	.0007[a]
HIGH SPEED SLOW DOWN	7.892852	.0014[a]	11.89375	.0001[a]
REDUCE SPEED IN WORK ZONE	4.952481	.0077[a]	6.319683	.0015[a]
YOU ARE SPEEDING SLOW DOWN	7.814545	.0014[a]	10.64841	.0001[a]

[a] Significance at 5% significance level.

These results further confirm that CMS messages influenced high-speed drivers to slow down as they travelled through the work zone. While the results from the tests using the whole population also showed significant reductions in vehicle speeds in some cases, these results are more important, as the effect of CMS on high-speed drivers is not diluted among the whole population data. Because the majority of vehicles in the whole population were not speeding, only the minority of drivers traveling above the threshold speed actually saw the messages. Thus, the effect of CMS on the average and 85th percentile speeds of the whole population was not as great as for the speeding vehicles who activated the messages when considered by themselves. This theory is confirmed by the results using only the data from the cameras, which focused solely on the high-speed vehicles. For these data, speeds are reducing, as indicated by the results of the *t* tests, and speed variance is also decreasing, as evidenced by the data in Table D-3, which shows that the high-speed drivers are converging to the same speed by the time they reach station 3.

A summary of significance test results is given in table 17 and significance ratings for speed characteristics are given in table 18.

SUMMARY OF RESULTS

Table 17 provides specific information regarding the results of each particular significance test conducted in the analysis, in effect whether each null hypothesis was accepted or rejected.

- Trends in average speeds and 85th percentile speeds observed from the camera data (Figures 9 and 10) show that all of the messages were effective in reducing the speeds of high-speed vehicles through the work zone.

- When station 1 speeds were broken down into two categories, 95-103 km/h and ≥ 104 km/h (59-64 mph and ≥ 65 mph), the differences in average speeds between the two categories at the three stations generally converged to zero as vehicles approached station 3. This trend suggests that CMS has a positive impact on reducing speed variance within the work zone.

- Trends in average speeds, 85th percentile speeds, and the percentages of vehicles speeding by any amount, by 8 km/h (5 mph) or more, and by 16 km/h (10 mph) or more observed from the whole population data show that all of the messages were effective in reducing vehicle speeds and the number of vehicles speeding through the work zone, although in some cases these reductions may not be significant.

- The odds ratios indicate that CMS was effective in reducing the odds for speeding by any amount, by 8 km/h (5 mph) or more, and by 16 km/h (10 mph) or more. Approximately three-fourths of the odds ratios calculated represented a potential reduction of 70% or greater in the number of vehicles speeding if CMS was used in the work zone.

Table 17. Summary of Significance Tests Results

ID Number	Purpose	Hypothesis Number	Type of Data	Table of Results	Final Results
1	To assess the effectiveness of the CMS by comparing the odds for speeding when using the CMS and when not using the CMS	---	*Whole Population Data*	Tables F-1 through F-7 (Appendix F)	The odds for speeding were reduced with the use of the CMS. Approximately three-fourths of the odds ratios calculated represented a potential reduction of 70% or greater in the number of vehicles speeding if the CMS was used in the work zone.
2	To determine if there was a significant difference in speeds when using any one of the 4 messages on the CMS	1 & 2	*Camera Data* Average and 85th Percentile Speeds	Table 6	No significant difference in speeds between any of the 4 messages for high-speeding vehicles. Do not reject null hypotheses 1 & 2
3	To determine if there were significant differences in the data obtained when the data collection team was present and not present at the work zone	3 - 6	*Whole Population Data* Average and 85th Percentile Speeds, Speed Variance	Table 7	No significant difference in speed data collected when data collection team was present and not present at the work zone. Do not reject null hypotheses 3 - 6.
4	To assess the effect of each message on speeds as compared to speeds when using MUTCD signing only	7 - 10	*Whole Population Data* Average and 85th Percentile Speeds, Speed Variance, Percentages of Vehicles Speeding	Table 8 & Tables 10 through 14	*Average Speeds**: Reject 8 & 10 at both stations; Reject 7 at station 3, 9 at station 2 *85th %ile Speeds**: Reject 7 - 10 at both stations *Speed variance**: Reject 8 - 10 at both stations; Do not reject 7 at both stations *% Spding Any Amt**: Reject 7 - 10 at both stations *% Spding $\geq$5 mph**: Reject 8 at station 3, 9 at station 2, and 10 at both stations; Do not reject 7 at both stations *% Spding $\geq$10 mph**: Do not reject 7 - 10 at both stations
5	To determine if there was a significant difference in speeds when using any one of the 4 messages on the CMS	11	*Whole Population Data* Average and 85th Percentile Speeds, Speed Variance, Percentage of Vehicles Speeding	Table 9	No significant difference in speeds between any of the 4 messages using whole population data. Do not reject null hypothesis 11 for any speed characteristic at either station 2 or 3.
6	To determine if the high-speeding vehicles were reducing vehicles speeds through the work zone	12 - 15	*Camera Data* Average Speeds (when Station 1 speeds were broken into two speed categories)	Tables 15 & 16	Significant reduction in average speeds for both speed categories. Reject null hypotheses 12 - 15 for comparison of station 1 to 2 as well as station 1 to 3

* Note: Null hypothesis 7 refers to "EXCESSIVE SPEED SLOW DOWN", 8 to "HIGH SPEED SLOW DOWN", 9 to "REDUCE SPEED IN WORK ZONE", and 10 to "YOU ARE SPEEDING SLOW DOWN."

Table 18. Significance Ratings of Speed Characteristics

	EXCESSIVE SPEED SLOW DOWN		HIGH SPEED SLOW DOWN		REDUCE SPEED IN WORK ZONE		YOU ARE SPEEDING SLOW DOWN	
	Station 2	Station 3	Station 2	Station 3	Station 2	Station 3	Station 2	Station 3
Average Speeds	No	Yes	Yes	Yes	Yes	No	Yes	Yes
85th Percentile Speeds	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Speed Vari-ance	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Percentage Speeding by Any Amount	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Percentage Speeding by 5 MPH or More	No	No	No	Yes	Yes	No	Yes	Yes
Percentage Speeding by 10 MPH or More	No	No	No	No	No	No	No	No

- The data from the work zone on I-81 North in Abingdon could not be used in the analysis as it was the only site that reduced the normal speed limit by 20 mph (the remaining six sites reduced the speed limit by 10 mph). From visual observation of the data, CMS did succeed in reducing speeds in the work zone; however, there were higher speed differences between the actual driving speeds and the posted speed limit of 45 mph than were observed at any of the other sites.

- There was no significant difference between any of the four messages in reducing the speeds of high-speed vehicles that were observed using the camera data.

- There was no significant difference between the data obtained when the data collection team was present at the work zone and when the data collection team was not present at the work zone.

- Using the average speeds calculated from the whole population data, it was found that the messages "YOU ARE SPEEDING SLOW DOWN" and "HIGH SPEED SLOW DOWN" significantly reduced speeds at stations 2 and 3 when compared to MUTCD signing only. "REDUCE SPEED IN WORK ZONE" was effective in significantly reducing speeds in the middle of the work zone, but its influence diminished at the end of the work zone at station 3. "EXCESSIVE SPEED SLOW DOWN" was effective in significantly reducing speeds at station 3 only.

- Using the 85th percentile speeds from the whole population data, all of the messages were effective in significantly reducing these speeds through the work zone at both stations 2 and 3.

- Using the speed variances from the whole population data, "EXCESSIVE SPEED SLOW DOWN" was the only message that did not significantly reduce variance at both stations 2 and 3. The remaining three messages were effective in significantly reducing variance at both stations within the work zone.

- Using the percentage of vehicles speeding by any amount, all of the messages were effective in significantly reducing the number of vehicles speeding through the work zone.

- Using the percentage of vehicles speeding by 8 km/h (5 mph) or more, only the message "YOU ARE SPEEDING SLOW DOWN" was effective in significantly reducing the number of vehicles speeding at this level at both stations 2 and 3. "EXCESSIVE SPEED SLOW DOWN" was the only message that did not significantly reduce the number of speeders at either of the two stations, while the remaining two messages significantly reduced speeds at one station each.

- Using the percentage of vehicles speeding by 16 km/h (10 mph) or more, none of the messages was effective in significantly reducing the number of vehicles speeding at this level. This reduction may not have been significant because of the relatively few drivers traveling at this speed. However, despite the fact that the difference was not significant, upon reviewing the data the number of drivers speeding by 10 mph or more was reduced with the use of CMS.

- When average speeds of vehicles at station 1, broken into the two categories of 95-103 km/h and ≥ 104.6 km/h (59-64 mph and ≥ 65 mph), were compared with the average speeds of the same vehicles at stations 2 and 3, all of the messages significantly reduced the average speeds of both high-speed vehicle groups at both stations within the work zone.

CONCLUSIONS

The following conclusions are made based on the literature search and the results of the analyses.

- The changeable message sign with radar unit is a dynamic speed control measure which is more effective than static MUTCD signs in altering driver behavior in work zones. Using personalized messages for high-speed drivers will result in these drivers being more inclined to reduce vehicle speeds in work zones.

- Upon testing CMS at seven sites on interstate highways in the state of Virginia, it was found that CMS is an effective means of reducing vehicle speeds and speed variance, and thereby increasing safety in work zones, as evidenced by the following:

  * The CMS is an effective means of reducing the number of vehicles speeding in the work zone. All of the messages on the CMS reduce the odds for speeding in the work zone by any amount, by 8 Km/h (5 mph) or more, and by 16 Km/h (10 mph) or more. In most cases, the use of the CMS resulted in the reduction of vehicles speeding by 50% or more.

  * All of the messages are effective in significantly reducing the average speeds of high-speeding vehicles, i.e., vehicles traveling 95 km/h (59 mph)

or faster in a 88.5 km/h (55 mph) work zone, when compared to vehicle speeds using MUTCD signing only.

* The average speeds of high-speed vehicles tend to converge by the time they reach station 3 at the end of the work zone. This results in a lower speed variance, which contributes to safer conditions in the work zone.

* All of the speed characteristics, average speeds, 85th percentile speeds, speed variance, and the percentages of vehicles speeding by any amount, by 8 km/h (5 mph) or more, and by 16 km/h (10 mph) or more, are reduced with the use of any of the 4 messages on CMS. These reductions may or may not be significant, as indicated by Table 18.

- When directly compared, there were no significant differences between the 4 messages with regard to their effect on high-speed vehicles as well as the whole population. However, based on the behavior of the whole population when the speeds using the messages were compared to speeds using MUTCD signing only, they were ranked in the following order:

* The message ''YOU ARE SPEEDING SLOW DOWN" was the most effective in significantly reducing average speeds, 85th percentile speeds, and speed variance of the whole population traveling through the work zone. In addition, it significantly reduced the total number of vehicles speeding in the work zone and the number of vehicles speeding by 8 km/h (5 mph) or more. The success of this message suggests that drivers responded more favorably to its personalized nature. The ''YOU ARE" emphasizes the warning message to the individual, as opposed to an advisory announcement only.

* The message ''HIGH SPEED SLOW DOWN" was the second most effective message displayed on CMS, possibly because it was so simple and easy to read by drivers.

* ''REDUCE SPEED IN WORK ZONE" was ranked as the third most effective. Its relative lack of success may be attributed to its resemblance to an advisory notice rather than an actual warning or threat that would induce drivers to slow down.

* Finally, ''EXCESSIVE SPEED SLOW DOWN" was the least effective of the four messages tested. Its inadequacy may lay in its appearance on the display board. As CMS only allows a certain number of letters per line, the smallest font had to be used to make the word ''EXCESSIVE" fit. This font, 3 x 7 (Narrow), may have been harder to read than the other three messages, which were simpler. In addition, the more formal terminology may have diminished the intensity of the warning for the average driver.

- The speed data obtained at the one work zone which reduced the normal speed limit by 32.2 km/h (20 mph) indicates that drivers may not have perceived the need to slow down to 72.4 km/h (45 mph). The large speed differences between the posted speed limit and actual driving speeds points out the need for a justifiable speed reduction based on an accurate assessment of work zone conditions.

RECOMMENDATIONS

The following recommendations are made regarding the use of CMS as a speed control measure in work zones and the direction of further research on this subject.

- CMS with radar unit is recommended as an effective speed control device to be used in work zones on interstate highways. In addition to reducing speeds, it is also effective in reducing speed variance, which could result in overall safer conditions in the work zone. The following guidelines are suggested for its use:

    * The threshold speed should be set at approximately 3 mph over the posted speed limit in order to warn drivers that they are exceeding maximum safe speed in the area.

    * CMS should be placed just before the beginning of the actual activity area, unobstructed by other signs so that it may be easily read and obtain the drivers' undivided attention.

    * When there is a taper and traffic is funneled into a single lane, it is suggested that CMS be placed so the radar will detect only one vehicle at a time, and that the display be seen clearly by that one vehicle alone. If more than one lane of traffic is permitted through the work zone, CMS should be placed so that both lanes can easily see the display board.

    * The message ''YOU ARE SPEEDING SLOW DOWN" is recommended for the display as it obtained the best response from the driving public. ''HIGH SPEED SLOW DOWN" may also be used and will obtain virtually the same results.

- This project determined that the CMS is effective in work zones for short-term applications, up to one week at a time. To assess its effectiveness for longer periods, it is recommended that a similar study be repeated as soon as possible, testing the usefulness of CMS on long-term applications and experimenting with various techniques which might expand its potential. Possible variations in its use include:

  - * The possibility of changing messages periodically to inject more spontaneity into its use and prevent indifference to the speed control effort from overusing one message.

  - * Investigating the use of CMS only during critical periods in the project when conditions change in the work zone.

  - * Testing new messages which provide information based on changing conditions in the work zone, used together with speed warning messages. This technique would examine the effectiveness of using sequence messages where more than one screen of information is read by the driver.

- Further study is also recommended to test the application of CMS in different environments -- type of highway, various reduced speed limits, number of lanes open to traffic, day or night operation, length of work zone, etc. One of the main objectives of this project was to determine to what extent and under what traffic conditions this speed control method would be most effective; this could not be fulfilled due to the lack of feasible work zones which met the criteria for site selection. By testing CMS in different conditions, more specific guidelines may be developed for its use and maximum benefit. (Three reasons why sites on primary highways failed to meet the selection criteria were hindrances to free flow traffic within the work zone: [1] stoplights, [2] crossovers or driveways, and [3] the presence of flaggers. While stoplights, crossovers and driveways cannot be removed from the site, in future undertakings plans for data collection could be made in conjunction traffic control plans at the work zone in advance of construction activities. By working together with project engineers or those responsible for developing the TCP, arrangements can be made to include CMS in the speed control effort, as opposed to flaggers or other devices, thereby allowing data collection.)

- Finally, the use of CMS with radar unit in conjunction with technologies such as photo-radar is recommended for future applications. If the central processing unit of the CMS could be modified to accept visual information and process it quickly enough to display it, it could prove to be quite valuable. This technique would allow the message to be more personalized, and therefore more threatening, as vehicle license plate numbers could be identified and displayed along with a warning message.

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APPENDIX A

SURVEY QUESTIONNAIRE

USING AN AUTOMATED DRIVER INFORMATION SYSTEM TO REDUCE SPEEDING THROUGH WORK ZONES

RESIDENT ENGINEERS' SURVEY

Location of start of Work Zone: (Please be specific: e.g., Route I-64 east bound 1.2 miles from Route 20 east) ____________________

____

____

Location of End of Work Zone: (Please be specific as above) ____________

____

Length of Work Zone: ____

Number of Lanes at Work Zone: ____________________________________

Number of Lanes to be Closed During Work Activities ________________

Approximate Start Date of Reconstruction/Construction: ______________

Approximate Completion Date of Work Activities: ____________________

Indicate Whether Day or Night Operation: __________________________

Approximate AADT at Work Site: ____________________________________

Residency: ____

Name of Resident Engineer: ______________________________________

Telephone Number of Resident Engineer: ____________________________

Please complete this form and return to:

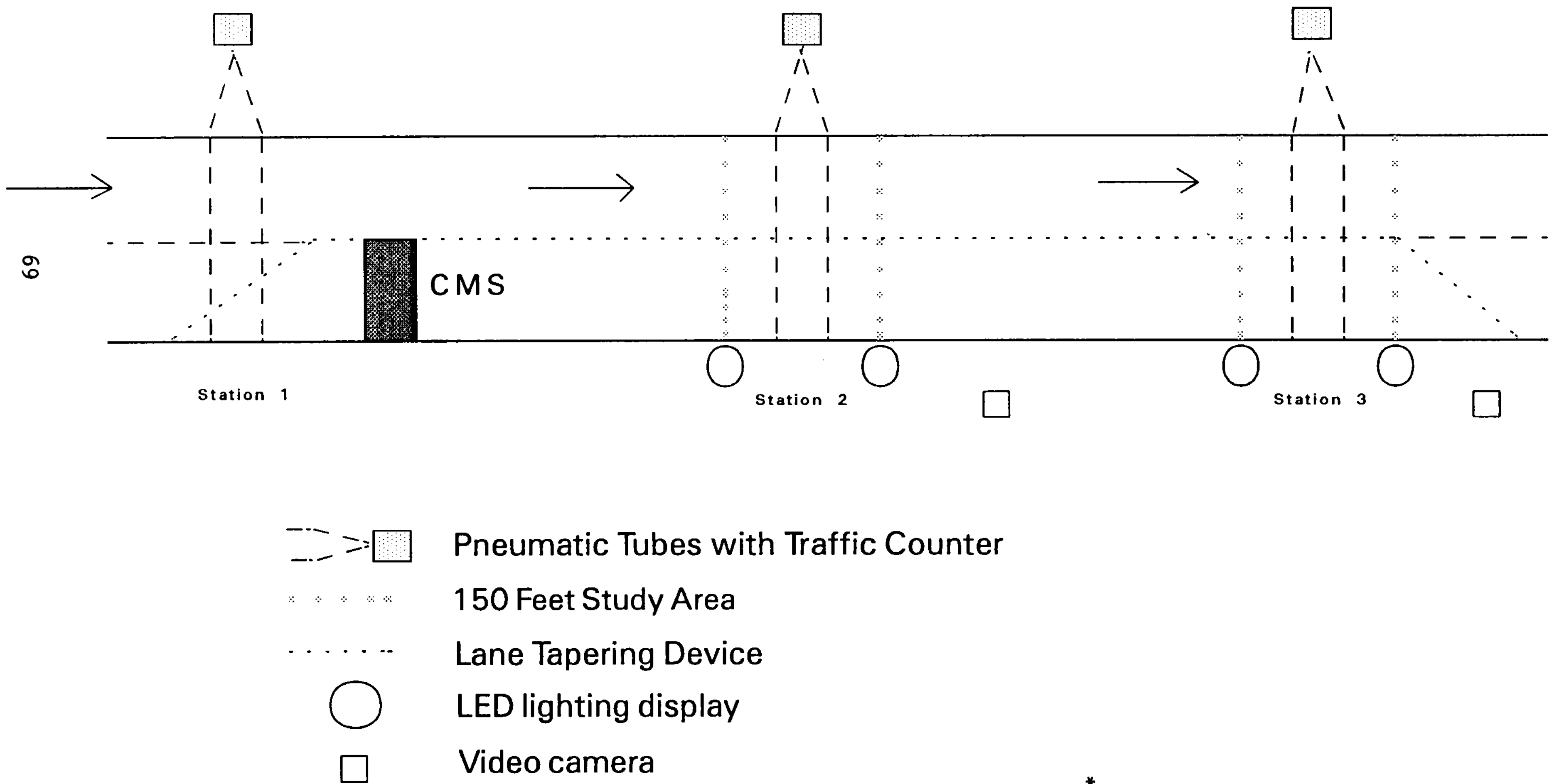
Nicholas J. Garber
Virginia Transportation Research Council
P.O. Box 3817, University Station
Charlottesville, Virginia 22903

APPENDIX B

DIAGRAM OF A TYPICAL WORK ZONE AREA

Diagram of Typical Work Zone Study Area*

2 Lane Highway Tapered to 1 Lane



* NOTE: Figure Not to Scale

APPENDIX C

SAMPLE DATA COLLECTION SHEET

ROUTE:__________
LOCATION:__________
COUNTY:__________
DIRECTION:__________
THRESHOLD SPEED:__________

NO. OF LANES:__________
LIGHTING CONDITION:__________
MESSAGE USED:__________
VOLUME:__________

DATE:__________

WORK ZONE STUDY
Data Collection Sheet

Time	Passenger Cars			Vans/ Pickups		Color of Vehicle								Truck Type		Station Velocity		
	Ṡ	M	L	S	R	Wh	Blk	Br	Rd	Blu	Mr	VBe	O	ST	TT	1	2	3

APPENDIX D

CAMERA DATA

TABLE D-1. AVERAGE SPEEDS (mph) USING CAMERA DATA

	EXCESSIVE SPEED SLOW DOWN			HIGH SPEED SLOW DOWN			REDUCE SPEED IN WORK ZONE			YOU ARE SPEEDING SLOW DOWN			SLOW DOWN NOW		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
81 South Buff. Gap	62.00	51.65	50.27	61.97	50.96	47.05	61.50	53.39	48.62	62.46	51.14	45.63		Not	
64 East Covington	62.17	46.82	43.07	62.95	48.45	43.90	62.40	49.82	45.80	63.01	47.98	41.11		Tested	
64 East Sht.Pump[1]	61.54	---	48.51	62.09	---	50.00	62.18	---	49.76	61.84	---	49.17		At	
81 North Bristol[1]	61.26	51.64	49.92	61.18	51.05	50.48	61.63	52.76	52.07	61.15	50.14	49.56		These	
81 North Abingdon[2]	55.81	38.30	---	55.43	39.23	34.56	56.44	42.72	41.65	54.92	38.68	36.73		Sites	
81 South Abingdon	61.79	44.62	45.64	61.56	47.03	47.19	61.66	45.27	45.94	61.64	44.66	46.52	61.66	44.76	45.94
64 East Shadwell	62.87	58.59	58.56	62.68	55.84	53.40	63.11	57.94	58.54	63.60	55.09	53.14	63.17	56.38	55.61

[1] Two lanes open
[2] Reduced to 45 mph
--- Indicates that speeds were incalculable because a problem was encountered with the videotapes and travel times were therefore unavailable.

TABLE D-2. 85TH PERCENTILE SPEEDS (mph) USING CAMERA DATA

	EXCESSIVE SPEED SLOW DOWN			HIGH SPEED SLOW DOWN			REDUCE SPEED IN WORK ZONE			YOU ARE SPEEDING SLOW DOWN			SLOW DOWN NOW		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
81 South Buff. Gap	65	57.89	55.79	66	56.82	53.83	64	59.00	54.79	66	59.00	52.90		Not	
64 East Covington	65	53.83	50.30	67	53.83	52.00	66	56.82	52.00	67	54.79	49.49		Tested	
64 East Sht.Pump[1]	64	---	54.79	65	---	54.79	65	---	54.79	64	---	54.79		At	
81 North Bristol[1]	64	57.89	55.79	63	57.89	55.79	64	59.00	57.89	64	56.82	54.79		These	
81 North Abingdon[2]	60	44.47	---	60	45.12	39.34	61	48.70	46.49	59	43.83	42.03		Sites	
81 South Abingdon	65	51.49	52.16	64	53.33	53.04	65	51.49	51.30	64	51.49	53.04	64	51.49	52.16
64 East Shadwell	65	61.36	62.62	65	57.89	56.82	65	61.36	62.62	66	60.16	56.82	66	59.00	59.00

[1] Two lanes open
[2] Reduced to 45 mph
--- Indicates that speeds were incalculable because a problem was encountered with the videotapes and travel times were therefore unavailable.

TABLE D-3. AVERAGE SPEEDS (mph) USING CAMERA DATA
(According to two categories of speeds)

	Speed Category	EXCESSIVE SPEED SLOW DOWN			HIGH SPEED SLOW DOWN			REDUCE SPEED IN WORK ZONE			YOU ARE SPEEDING SLOW DOWN			SLOW DOWN NOW		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
81 South Buff. Gap	59-64	61.0	50.9	50.1	60.8	49.7	46.3	60.6	53.0	48.5	61.1	50.0	43.3			
	≥ 65	66.6	54.3	50.8	66.7	55.2	49.9	66.7	55.8	49.2	66.9	55.1	48.3		Not	
64 East Covington	59-64	61.0	46.2	42.4	61.1	48.4	43.7	60.9	48.5	44.7	61.4	47.6	40.7			
	≥ 65	66.5	49.1	45.7	67.5	48.6	44.4	66.5	53.6	48.6	67.5	49.5	42.3		Tested	
64 East Sht. Pump[1]	59-64	60.8	---	48.3	61.1	---	49.8	61.2	---	49.5	61.0	---	48.7			
	≥ 65	66.4	---	52.6	66.6	---	49.8	66.5	---	51.0	66.7	---	51.7		At	
81 North Bristol[1]	59-64	60.6	51.3	49.5	60.6	51.0	50.4	61.1	52.4	51.7	60.5	50.1	49.0			
	≥ 65	66.6	54.1	54.1	66.5	52.0	51.7	66.6	56.2	56.2	66.0	49.6	51.2		These	
81 North Abingdon[2]	49-54	52.1	37.7	---	52.2	38.3	34.1	52.3	41.2	40.6	51.6	38.5	36.3			
	≥ 55	58.9	38.8	---	58.3	40.0	35.0	59.3	43.8	42.3	58.8	38.9	37.3		Sites	
81 South Abingdon	59-64	60.9	44.3	45.3	61.0	46.5	46.8	60.8	45.2	45.9	60.9	44.7	46.5	60.9	44.3	45.7
	≥ 65	66.4	46.1	47.6	66.0	51.3	50.6	66.4	45.8	45.9	66.1	44.6	46.8	66.5	47.6	47.6
64 East Shadwell	59-64	61.6	58.3	58.3	61.2	54.9	53.3	61.7	56.9	57.6	61.8	55.0	53.0	61.6	55.5	55.0
	≥ 65	66.8	59.5	59.3	66.8	58.5	54.7	67.0	60.8	61.2	66.3	55.3	53.3	66.3	58.1	56.9

[1] Two lanes open
[2] Reduced to 45 mph
--- Indicates that speeds were incalculable because a problem was encountered with the videotapes and travel times were therefore unavailable.

APPENDIX E

WHOLE POPULATION DATA

TABLE E-1. AVERAGE SPEEDS (mph) USING WHOLE POPULATION DATA
(with cameras on top, without cameras on bottom in parentheses)

	NO CMS			EXCESSIVE SPEED SLOW DOWN			HIGH SPEED SLOW DOWN			REDUCE SPEED IN WORK ZONE			YOU ARE SPEEDING SLOW DOWN			SLOW DOWN NOW		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
81 South Buff. Gap	---	56.2	55.7	51.9 ---	--- ---	48.8 ---	51.8 (53.4)	49.7 (50.9)	48.9 (50.4)	52.8 ---	50.9 ---	49.6 ---	52.6 (52.9)	49.8 (50.3)	49.0 (49.6)		Not	
64 East Covington	55.5	52.8	53.4	50.7 (51.6)	48.9 (49.4)	49.4 (49.7)	51.7 (51.7)	48.9 (49.5)	50.0 (51.9)	51.7 ---	49.3 ---	50.0 ---	50.9 ---	48.6 ---	49.1 ---		Tested	
64 East Sht.Pump[1]	60.9	62.1	61.2	57.4 (58.4)	55.5 (56.6)	52.2 (54.9)	56.2 ---	54.1 ---	52.8 ---	57.1 (58.3)	55.3 (56.9)	53.2 (55.6)	56.9 ---	55.5 ---	52.7 ---		At	
81 North Bristol[1]	57.6	56.7	53.9	--- (55.9)	51.0 (53.7)	50.1 (53.1)	--- ---	50.5 (51.8)	50.3 (51.5)	--- ---	52.1 (53.1)	51.2 (51.8)	--- ---	50.9 (51.4)	50.0 (50.0)		These	
81 North Abingdon[2]	52.6	53.3	51.9	51.0 (50.9)	47.5 (47.9)	42.7 (48.0)	50.6 ---	48.4 ---	47.7 ---	51.1 (50.4)	48.2 (48.8)	47.4 (48.3)	50.6 ---	48.0 ---	42.6 ---		Sites	
81 South Abingdon	57.5	52.7	55.5	54.1 (55.1)	--- ---	49.7 (50.4)	54.6 (53.9)	--- ---	50.5 (50.1)	54.1 (55.2)	49.1 (50.2)	50.4 (51.6)	54.2 (55.1)	49.2 (49.1)	52.2 (50.1)	56.5 ---	50.7 ---	52.9 ---
64 East Shadwell	61.3	56.1	65.2	60.4 (60.0)	52.8 (52.6)	58.5 (58.8)	59.6 (59.7)	52.0 (52.2)	55.5 (57.3)	60.5 (59.3)	52.8 (51.5)	59.6 (55.8)	59.9 (58.3)	50.5 (50.3)	54.4 (53.6)	59.2 (59.1)	50.8 (51.6)	54.8 (55.8)

[1] Two lanes open
[2] Reduced to 45 mph
--- Indicates that speed and volume data was unavailable as a result of pneumatic tube failure or traffic counter memory loss.

TABLE E-2. 85TH PERCENTILE SPEEDS (mph) USING WHOLE POPULATION DATA
(with cameras on top, without cameras on bottom in parentheses)

	NO CMS			EXCESSIVE SPEED SLOW DOWN			HIGH SPEED SLOW DOWN			REDUCE SPEED IN WORK ZONE			YOU ARE SPEEDING SLOW DOWN			SLOW DOWN NOW		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
81 South Buff. Gap	---	61.5	61.2	56.3 ---	--- ---	53.2 ---	55.9 (58.0)	52.4 (54.6)	51.1 (54.0)	57.5 ---	54.2 ---	52.3 ---	57.5 (56.8)	52.7 (53.2)	51.4 (52.3)		Not	
64 East Covington	60.7	57.6	59.0	54.4 (56.0)	51.5 (52.7)	51.7 (51.5)	55.3 (56.5)	51.5 (53.1)	53.5 (57.0)	55.5 ---	51.8 ---	51.4 ---	54.8 ---	50.5 ---	51.2 ---		Tested	
64 East Sht.Pump[1]	63.2	64.5	63.8	60.9 (61.7)	58.8 (60.4)	55.9 (58.6)	60.6 ---	57.5 ---	55.5 ---	60.7 (61.7)	58.4 (61.0)	56.3 (59.5)	60.5 ---	59.5 ---	56.7 ---		At	
81 North Bristol[1]	60.9	60.0	57.0	--- (59.0)	53.6 (57.0)	52.5 (56.0)	--- ---	53.2 (55.1)	52.8 (54.3)	--- ---	55.5 (56.1)	53.9 (54.5)	--- ---	53.4 (54.3)	52.2 (52.1)		These	
81 North Abingdon[2]	55.6	56.8	54.9	53.6 (53.8)	48.5 (50.2)	44.3 (49.3)	53.5 ---	50.3 ---	48.8 ---	53.8 (53.1)	49.6 (50.8)	47.9 (49.8)	53.2 ---	50.6 ---	43.9 ---		Sites	
81 South Abingdon	60.9	55.9	58.5	57.4 (58.5)	--- ---	51.1 (51.5)	57.7 (57.3)	--- ---	51.8 (51.6)	57.7 (59.0)	49.5 (52.0)	51.9 (55.1)	57.5 (58.9)	50.2 (50.0)	51.4 (51.7)	60.2 ---	52.6 ---	55.0 ---
64 East Shadwell	64.6	59.3	66.1	63.6 (63.4)	55.7 (55.6)	61.7 (61.7)	63.1 (63.1)	55.4 (55.1)	59.0 (60.7)	63.6 (62.6)	56.1 (53.6)	63.1 (58.5)	62.6 (61.3)	52.2 (51.6)	56.7 (55.9)	62.3 (62.5)	52.3 (54.1)	57.6 (62.5)

[1] Two lanes open
[2] Reduced to 45 mph
--- Indicates that speed and volume data was unavailable as a result of pneumatic tube failure or traffic counter memory loss.

TABLE E-3. SPEED VARIANCES (mph) USING WHOLE POPULATION DATA
(with cameras on top, without cameras on bottom in parentheses)

	NO CMS			EXCESSIVE SPEED SLOW DOWN			HIGH SPEED SLOW DOWN			REDUCE SPEED IN WORK ZONE			YOU ARE SPEEDING SLOW DOWN			SLOW DOWN NOW		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
81 South Buff. Gap	---	31.8	33.2	24.4 ---	--- ---	16.9 ---	25.1 (28.2)	14.8 (19.2)	12.4 (18.8)	27.1 ---	18.4 ---	13.9 ---	29.2 (22.5)	16.8 (16.3)	12.9 (14.1)		Not	
64 East Covington	34.9	28.2	33.1	20.1 (24.6)	13.1 (14.7)	18.2 (17.4)	21.1 (25.5)	14.5 (17.0)	20.1 (30.1)	21.2 ---	13.0 ---	16.6 ---	20.1 ---	13.6 ---	14.2 ---		Tested	
64 East Sht.Pump[1]	24.0	30.7	31.4	29.6 (31.6)	35.8 (34.6)	38.3 (40.4)	31.6 ---	29.3 ---	25.4 ---	29.3 (30.3)	28.6 (36.0)	26.0 (35.7)	28.5 ---	33.8 ---	33.0 ---		At	
81 North Bristol[1]	31.8	31.2	26.4	--- (26.4)	20.4 (26.4)	18.2 (23.3)	--- ---	20.6 (23.0)	18.4 (19.9)	--- ---	23.0 (24.9)	19.2 (18.6)	--- ---	20.7 (22.7)	16.0 (16.5)		These	
81 North Abingdon[2]	23.0	33.9	25.5	21.4 (20.4)	12.0 (12.0)	13.3 (40.1)	20.7 ---	13.8 ---	9.9 ---	20.2 (20.2)	13.1 (15.2)	9.4 (12.0)	21.0 ---	15.1 ---	12.9 ---		Sites	
81 South Abingdon	29.4	23.0	33.2	27.4 (28.3)	--- ---	10.1 (13.5)	27.5 (25.8)	--- ---	20.3 (10.7)	28.4 (30.6)	7.7 (13.9)	20.0 (27.9)	26.2 (30.1)	8.3 (8.3)	20.6 (12.1)	30.0 ---	16.6 ---	35.3 ---
64 East Shadwell	26.3	23.9	37.4	23.4 (25.5)	21.3 (23.1)	32.7 (33.6)	28.4 (25.4)	22.3 (22.0)	36.4 (31.4)	24.6 (23.8)	22.5 (41.0)	35.1 (26.9)	22.0 (20.4)	14.9 (37.4)	21.2 (21.4)	23.3 (21.6)	15.7 (40.9)	24.4 (25.6)

[1] Two lanes open
[2] Reduced to 45 mph
--- Indicates that speed and volume data was unavailable as a result of pneumatic tube failure or traffic counter memory loss.

TABLE E-4. PERCENTAGE OF VEHICLES SPEEDING BY ANY AMOUNT USING WHOLE POPULATION DATA
(with cameras on top, without cameras on bottom in parentheses)

	NO CMS			EXCESSIVE SPEED SLOW DOWN			HIGH SPEED SLOW DOWN			REDUCE SPEED IN WORK ZONE			YOU ARE SPEEDING SLOW DOWN			SLOW DOWN NOW		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
81 South Buff. Gap	---	55.2	52.1	24.6 ---	--- ---	10.3 ---	22.3 (33.8)	9.1 (17.4)	6.0 (14.8)	31.1 ---	15.5 ---	8.6 ---	27.6 (30.2)	10.2 (11.1)	6.6 (8.0)		Not	
64 East Covington	50.8	30.2	34.4	15.5 (20.5)	8.0 (10.3)	8.4 (16.0)	22.5 (20.3)	6.7 (12.9)	14.0 (25.0)	20.2 ---	4.9 ---	15.6 ---	17.7 ---	5.6 ---	4.5 ---		Tested	
64 East Sht.Pump[1]	81.9	82.0	77.7	56.5 (60.8)	36.1 (45.9)	21.0 (32.4)	46.4 ---	30.0 ---	19.3 ---	56.6 (63.5)	41.5 (48.9)	24.1 (40.2)	52.3 ---	38.9 ---	23.0 ---		At	
81 North Bristol[1]	55.3	49.8	31.3	--- (44.6)	13.2 (31.4)	9.3 (26.4)	--- ---	11.9 (19.5)	9.6 (15.8)	--- ---	21.4 (27.1)	13.7 (17.0)	--- ---	12.1 (16.0)	7.6 (7.5)		These	
81 North Abingdon[2]	93.1	92.6	89.6	86.1 (87.6)	60.7 (65.0)	--- (69.0)	85.7 ---	68.7 ---	64.3 ---	89.4 (83.0)	70.1 (74.7)	58.9 (70.7)	84.2 ---	57.4 ---	--- ---		Sites	
81 South Abingdon	55.8	22.7	35.9	31.5 (38.9)	--- ---	5.0 (5.8)	34.4 (31.5)	--- ---	7.4 (5.2)	31.3 (38.7)	2.6 (6.8)	8.2 (18.6)	32.6 (37.2)	2.0 (2.2)	5.5 (6.2)	47.6 ---	11.4 ---	17.2 ---
64 East Shadwell	83.8	47.7	89.9	75.9 (81.0)	20.7 (23.2)	62.0 (58.7)	68.6 (71.7)	19.7 (19.5)	35.9 (49.8)	79.1 (70.4)	22.9 (12.7)	67.9 (43.8)	77.1 (63.8)	8.6 (8.4)	31.2 (24.5)	69.8 (71.7)	10.4 (15.3)	35.1 (43.4)

[1] Two lanes open
[2] Reduced to 45 mph
--- Indicates that speed and volume data was unavailable as a result of pneumatic tube failure or traffic counter memory loss.

TABLE E-5. PERCENTAGE OF VEHICLES SPEEDING BY 5 MPH OR MORE USING WHOLE POPULATION DATA
(with cameras on top, without cameras on bottom in parentheses)

	NO CMS			EXCESSIVE SPEED SLOW DOWN			HIGH SPEED SLOW DOWN			REDUCE SPEED IN WORK ZONE			YOU ARE SPEEDING SLOW DOWN			SLOW DOWN NOW		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
81 South Buff. Gap	---	21.6	20.7	5.7 ---	--- ---	3.1 ---	6.3 (10.0)	1.9 (3.7)	1.8 (3.5)	8.3 ---	3.0 ---	1.5 ---	9.5 (6.4)	2.6 (2.8)	1.1 (1.6)		Not	
64 East Covington	17.8	9.2	12.1	3.2 (7.1)	1.1 (0)	4.8 (0)	4.7 (6.8)	3.4 (1.2)	3.5 (8.6)	5.3 ---	1.5 ---	1.7 ---	3.4 ---	1.6 ---	1.8 ---		Tested	
64 East Sht.Pump[1]	37.7	42.6	36.5	19.5 (25.1)	12.5 (16.1)	7.9 (12.5)	17.0 ---	9.5 ---	6.1 ---	18.7 (23.9)	10.0 (19.1)	5.2 (13.3)	17.2 ---	13.9 ---	6.9 ---		At	
81 North Bristol[1]	18.9	15.3	6.2	--- (11.6)	2.3 (5.9)	1.2 (3.7)	--- ---	1.9 (2.8)	1.2 (1.4)	--- ---	2.0 (4.1)	1.1 (1.8)	--- ---	2.4 (2.5)	0.5 (1.2)		These	
81 North Abingdon[2]	52.2	54.0	43.4	37.6 (36.5)	10.7 (11.5)	--- (11.8)	34.8 ---	15.8 ---	10.0 ---	37.7 (33.0)	13.7 (18.1)	9.9 (14.3)	33.7 ---	17.1 ---	--- ---		Sites	
81 South Abingdon	19.0	4.7	11.3	8.1 (11.2)	--- ---	0 (1.2)	9.6 (7.1)	--- ---	3.0 (0.4)	9.8 (12.3)	0.3 (1.2)	3.4 (6.4)	8.2 (12.2)	0.3 (0.2)	0.2 (1.1)	16.0 ---	1.3 ---	8.3 ---
64 East Shadwell	42.4	12.1	56.3	32.2 (35.4)	5.5 (4.6)	21.4 (22.4)	31.1 (30.9)	4.7 (4.3)	12.9 (17.6)	37.5 (28.8)	4.4 (21.3)	28.0 (11.3)	34.3 (20.5)	1.9 (1.8)	5.4 (5.3)	27.0 (26.3)	1.8 (1.1)	8.4 (11.3)

[1] Two lanes open
[2] Reduced to 45 mph
--- Indicates that speed and volume data was unavailable as a result of pneumatic tube failure or traffic counter memory loss.

TABLE E-6. PERCENTAGE OF VEHICLES SPEEDING BY 10 MPH OR MORE USING WHOLE POPULATION DATA
(with cameras on top, without cameras on bottom in parentheses)

	NO CMS			EXCESSIVE SPEED SLOW DOWN			HIGH SPEED SLOW DOWN			REDUCE SPEED IN WORK ZONE			YOU ARE SPEEDING SLOW DOWN			SLOW DOWN NOW		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
81 South Buff. Gap	---	7.8	6.9	1.5 ---	--- ---	0.7 ---	2.5 (3.3)	0.4 (0.4)	0.4 (0.5)	2.4 ---	0.7 ---	0.3 ---	3.3 (1.6)	0.7 (0.8)	0.4 (0.3)		Not	
64 East Covington	5.8	2.3	4.8	1.1 (0.6)	0 (0)	0 (0)	1.9 (1.1)	0.7 (0)	1.8 (2.6)	1.3 ---	1.0 ---	0.6 ---	1.2 ---	0.8 ---	1.8 ---		Tested	
64 East Sht.Pump[1]	10.8	17.1	14.3	5.5 (8.3)	6.3 (7.2)	N/A[3]	4.3 ---	3.0 ---	1.8 ---	3.6 (8.0)	3.2 (7.7)	2.2 (5.5)	4.5 ---	5.9 ---	N/A[3]		At	
81 North Bristol[1]	5.2	4.0	1.3	--- (2.2)	0.2 (1.1)	0.3 (0.9)	--- ---	0.3 (0.5)	0.3 (0.2)	--- ---	0.4 (0.7)	0 (0)	--- ---	0.3 (0.4)	0.2 (0.1)		These	
81 North Abingdon[2]	22.2	27.6	18.2	13.3 (13.9)	2.2 (2.6)	--- (2.4)	13.3 ---	5.2 ---	2.0 ---	14.2 (11.4)	4.0 (5.3)	2.3 (3.1)	12.0 ---	3.9 ---	--- ---		Sites	
81 South Abingdon	6.0	1.0	5.5	2.4 (3.0)	--- ---	0 (0.7)	2.2 (1.9)	--- ---	2.3 (0.1)	2.2 (3.4)	0 (0.6)	2.2 (3.8)	1.7 (3.4)	0 (0)	0.2 (0.5)	4.4 ---	0.6 ---	5.8 ---
64 East Shadwell	17.1	2.1	28.0	13.1 (12.7)	0.6 (0.5)	9.3 (8.8)	12.2 (11.4)	0.5 (0.5)	6.5 (7.0)	13.1 (9.5)	0.4 (0.3)	11.9 (3.6)	9.0 (6.5)	0.1 (0.3)	1.8 (2.1)	9.1 (9.2)	0.2 (0.2)	2.2 (2.7)

[1] Two lanes open
[2] Reduced to 45 mph
[3] Counters bins were mistakenly programmed to range from 42 mph - 64 mph; therefore, the exact figures for speeds > 65 mph, i.e., 10 mph above the speed limit, were indeterminable for this station.
--- Indicates that speed and volume data was unavailable as a result of pneumatic tube failure or traffic counter memory loss.

APPENDIX F

ODDS RATIOS TABLES

TABLE F-1. ODDS RATIOS[1] AT I-81 SOUTH BUFFALO GAP

	STATION 1			STATION 2			STATION 3		
	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE
ODDS FOR SPEEDING WITH NO CMS[2]	---	---	---	1.23	.48	.17	1.09	.43	.14
EXCESSIVE SPEED SLOW DOWN WITH CAMERAS	---	---	---	---	---	---	.11 (89%)	.081 (92%)	.055 (95%)
WITHOUT CAMERAS	---	---	---	---	---	---	---	---	---
HIGH SPEED SLOW DOWN WITH CAMERAS	---	---	---	.081 (92%)	.044 (96%)	.028 (97%)	.059 (94%)	.044 (96%)	.034 (97%)
WITHOUT CAMERAS	---	---	---	.17 (83%)	.094 (91%)	.026 (97%)	.16 (84%)	.095 (91%)	.039 (96%)
REDUCE SPEED IN WORK ZONE WITH CAMERAS	---	---	---	.15 (85%)	.073 (93%)	.048 (95%)	.086 (91%)	.040 (96%)	.026 (97%)
WITHOUT CAMERAS	---	---	---	---	---	---	---	---	---
YOU ARE SPEEDING SLOW DOWN WITH CAMERAS	---	---	---	.089 (91%)	.060 (94%)	.046 (95%)	.065 (94%)	.028 (97%)	.034 (97%)
WITHOUT CAMERAS	---	---	---	.10 (90%)	.067 (93%)	.051 (95%)	.080 (92%)	.040 (96%)	.025 (98%)
SLOW DOWN NOW WITH CAMERAS				NOT TESTED	AT	THIS SITE			
WITHOUT CAMERAS									

[1] The percentage reduction corresponding to the odds ratio is shown in parentheses.
[2] These are the values that were used to calculate the odds ratios.
--- Indicates that speed and volume data was unavailable as a result of pneumatic tube failure or traffic counter memory loss.

TABLE F-2. ODDS RATIOS[1] AT I-64 EAST COVINGTON

	STATION 1			STATION 2			STATION 3		
	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE
ODDS FOR SPEEDING WITH NO CMS[2]	1.03	.36	.12	.43	.13	.033	.53	.18	.073
EXCESSIVE SPEED SLOW DOWN WITH CAMERAS	.17 (83%)	.11 (89%)	.11 (89%)	.20 (80%)	.092 (81%)	0 (100%)	.17 (83%)	.29 (71%)	0 (100%)
WITHOUT CAMERAS	.25 (75%)	.25 (75%)	.068 (93%)	.26 (74%)	0 (100%)	0 (100%)	.36 (64%)	0 (100%)	0 (100%)
HIGH SPEED SLOW DOWN WITH CAMERAS	.28 (72%)	.17 (83%)	.20 (80%)	.17 (83%)	.28 (72%)	.22 (78%)	.30 (70%)	.23 (77%)	.27 (73%)
WITHOUT CAMERAS	.25 (75%)	.24 (76%)	.12 (88%)	.35 (65%)	.11 (89%)	0 (100%)	.62 (38%)	.61 (39%)	.47 (53%)
REDUCE SPEED IN WORK ZONE WITH CAMERAS	.24 (76%)	.18 (82%)	.13 (87%)	.12 (88%)	.12 (88%)	.30 (70%)	.36 (64%)	.11 (89%)	.090 (91%)
WITHOUT CAMERAS	---	---	---	---	---	---	---	---	---
YOU ARE SPEEDING SLOW DOWN WITH CAMERAS	.20 (80%)	.11 (89%)	.13 (87%)	.14 (86%)	.13 (87%)	.26 (74%)	.089 (91%)	.11 (89%)	.26 (74%)
WITHOUT CAMERAS	---	---	---	---	---	---	---	---	---
SLOW DOWN NOW WITH CAMERAS				NOT TESTED	AT	THIS SITE			
WITHOUT CAMERAS									

[1] The percentage reduction corresponding to the odds ratio is shown in parentheses.
[2] These are the values that were used to calculate the odds ratios.
--- Indicates that speed and volume data was unavailable as a result of pneumatic tube failure or traffic counter memory loss.

TABLE F-3. ODDS RATIOS[1] AT I-64 EAST SHORT PUMP

	STATION 1			STATION 2			STATION 3		
	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE
ODDS FOR SPEEDING WITH NO CMS[2]	4.53	2.08	.60	4.56	2.37	.95	3.49	1.64	.64
EXCESSIVE SPEED SLOW DOWN WITH CAMERAS	.29 (71%)	.22 (78%)	.22 (78%)	.12 (88%)	.084 (92%)	.11 (89%)	.077 (92%)	.061 (94%)	N/A[3]
WITHOUT CAMERAS	.34 (66%)	.31 (69%)	.35 (65%)	.19 (81%)	.13 (87%)	.14 (86%)	.14 (86%)	.11 (89%)	N/A
HIGH SPEED SLOW DOWN WITH CAMERAS	.19 (81%)	.15 (85%)	.14 (86%)	.094 (91%)	.059 (94%)	.044 (96%)	.069 (93%)	.046 (95%)	.036 (96%)
WITHOUT CAMERAS	---	---	---	---	---	---	---	---	---
REDUCE SPEED IN WORK ZONE WITH CAMERAS	.29 (71%)	.21 (79%)	.14 (86%)	.16 (84%)	.072 (93%)	.058 (94%)	.092 (91%)	.042 (96%)	.045 (96%)
WITHOUT CAMERAS	.38 (62%)	.32 (68%)	.37 (63%)	.21 (79%)	.16 (84%)	.16 (84%)	.19 (81%)	.13 (87%)	.15 (85%)
YOU ARE SPEEDING SLOW DOWN WITH CAMERAS	.24 (76%)	.17 (83%)	.16 (84%)	.14 (86%)	.097 (90%)	.11 (89%)	.086 (91%)	.054 (95%)	N/A[3]
WITHOUT CAMERAS	---	---	---	---	---	---	---	---	---
SLOW DOWN NOW WITH CAMERAS				NOT TESTED	AT	THIS SITE			
WITHOUT CAMERAS									

[1] The percentage reduction corresponding to the odds ratio is shown in parentheses.
[2] These are the values that were used to calculate the odds ratios.
[3] Counter bins were mistakenly programmed to range from 42 mph - 64 mph; therefore, the exact figures for speeds > 65 mph, i.e., 10 mph above the speed limit, were indeterminable for this station.
--- Indicates that speed and volume data was unavailable as a result of pneumatic tube failure or traffic counter memory loss.

TABLE F-4. ODDS RATIOS[1] AT I-81 NORTH BRISTOL

	STATION 1			STATION 2			STATION 3		
	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE
ODDS FOR SPEEDING WITH NO CMS[2]	1.24	.42	.12	.99	.30	.081	.46	.091	.019
EXCESSIVE SPEED SLOW DOWN WITH CAMERAS	---	---	---	.15 (85%)	.087 (91%)	.022 (98%)	.22 (78%)	.14 (86%)	.20 (80%)
WITHOUT CAMERAS	.65 (35%)	.50 (50%)	.33 (67%)	.46 (54%)	.29 (71%)	.20 (80%)	.78 (22%)	.55 (45%)	.63 (37%)
HIGH SPEED SLOW DOWN WITH CAMERAS	---	---	---	.13 (87%)	.070 (93%)	.036 (96%)	.24 (76%)	.15 (85%)	.19 (81%)
WITHOUT CAMERAS	---	---	---	.24 (76%)	.12 (88%)	.072 (93%)	.41 (59%)	.19 (81%)	.14 (86%)
REDUCE SPEED IN WORK ZONE WITH CAMERAS	---	---	---	.27 (73%)	.087 (91%)	.070 (93%)	.35 (65%)	.13 (87%)	0 (100%)
WITHOUT CAMERAS	---	---	---	.37 (63%)	.19 (81%)	.12 (88%)	.43 (57%)	.23 (77%)	0 (100%)
YOU ARE SPEEDING SLOW DOWN WITH CAMERAS	---	---	---	.14 (86%)	.090 (91%)	.042 (96%)	.18 (82%)	.058 (94%)	.095 (91%)
WITHOUT CAMERAS	---	---	---	.19 (81%)	.10 (90%)	.052 (95%)	.18 (82%)	.14 (86%)	.084 (92%)
SLOW DOWN NOW WITH CAMERAS				NOT TESTED	AT	THIS SITE			
WITHOUT CAMERAS									

[1] The percentage reduction corresponding to the odds ratio is shown in parentheses.
[2] These are the values that were used to calculate the odds ratios.
--- Indicates that speed and volume data was unavailable as a result of pneumatic tube failure or traffic counter memory loss.

TABLE F-5. ODDS RATIOS[1] AT I-81 NORTH ABINGDON

	STATION 1			STATION 2			STATION 3		
	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE
ODDS FOR SPEEDING WITH NO CMS[2]	13.55	7.59	3.22	12.50	7.29	3.72	8.60	4.17	1.75
EXCESSIVE SPEED SLOW DOWN WITH CAMERAS	.46 (54%)	.36 (64%)	.30 (70%)	.12 (88%)	.037 (96%)	.015 (99%)	.022 (98%)	.0046 (99.9%)	.0046 (99.9%)
WITHOUT CAMERAS	.52 (48%)	.39 (61%)	.35 (65%)	.15 (85%)	.044 (96%)	.020 (98%)	.26 (74%)	.091 (91%)	.045 (96%)
HIGH SPEED SLOW DOWN WITH CAMERAS	.44 (56%)	.32 (68%)	.29 (71%)	.18 (82%)	.070 (93%)	.043 (96%)	.21 (79%)	.067 (93%)	.031 (97%)
WITHOUT CAMERAS	---	---	---	---	---	---	---	---	---
REDUCE SPEED IN WORK ZONE WITH CAMERAS	.62 (38%)	.47 (53%)	.41 (59%)	.19 (81%)	.063 (94%)	.035 (97%)	.17 (83%)	.058 (94%)	.032 (97%)
WITHOUT CAMERAS	.36 (64%)	.26 (74%)	.21 (79%)	.24 (76%)	.10 (90%)	.056 (94%)	.28 (72%)	.12 (88%)	.057 (94%)
YOU ARE SPEEDING SLOW DOWN WITH CAMERAS	.39 (61%)	.28 (72%)	.24 (76%)	.11 (89%)	.055 (95%)	.024 (98%)	.020 (98%)	.0053 (99.9%)	.0055 (99.9%)
WITHOUT CAMERAS	---	---	---	---	---	---	---	---	---
SLOW DOWN NOW WITH CAMERAS				NOT TESTED	AT	THIS SITE			
WITHOUT CAMERAS									

[1] The percentage reduction corresponding to the odds ratio is shown in parentheses.
[2] These are the values that were used to calculate the odds ratios.
--- Indicates that speed and volume data was unavailable as a result of pneumatic tube failure or traffic counter memory loss.

TABLE F-6. ODDS RATIOS[1] AT I-81 SOUTH ABINGDON

	STATION 1			STATION 2			STATION 3		
	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE
ODDS FOR SPEEDING WITH NO CMS[2]	1.26	.43	.13	.29	.061	.013	.56	.18	.086
EXCESSIVE SPEED SLOW DOWN WITH CAMERAS	.37 (63%)	.28 (72%)	.26 (74%)	---	---	---	.091 (91%)	0 (100%)	0 (100%)
WITHOUT CAMERAS	.51 (49%)	.42 (58%)	.38 (62%)	---	---	---	.11 (89%)	.072 (93%)	.090 (91%)
HIGH SPEED SLOW DOWN WITH CAMERAS	.42 (58%)	.35 (65%)	.26 (74%)	---	---	---	.14 (86%)	.18 (82%)	.29 (71%)
WITHOUT CAMERAS	.37 (63%)	.23 (77%)	.22 (78%)	---	---	---	.098 (90%)	.021 (98%)	.015 (99%)
REDUCE SPEED IN WORK ZONE WITH CAMERAS	.37 (63%)	.33 (67%)	.25 (75%)	.090 (91%)	.054 (95%)	0 (100%)	.16 (84%)	.21 (79%)	.28 (72%)
WITHOUT CAMERAS	.50 (50%)	.47 (53%)	.42 (58%)	.59 (41%)	.49 (51%)	1.23	.41 (59%)	.44 (56%)	.55 (45%)
YOU ARE SPEEDING SLOW DOWN WITH CAMERAS	.38 (62%)	.28 (72%)	.19 (81%)	.069 (93%)	.048 (95%)	0 (100%)	.11 (89%)	.0094 (99%)	.020 (98%)
WITHOUT CAMERAS	.47 (53%)	.44 (56%)	.42 (58%)	.079 (92%)	.034 (97%)	0 (100%)	.12 (88%)	.067 (93%)	.056 (94%)
SLOW DOWN NOW WITH CAMERAS	.72 (28%)	.72 (28%)	.64 (36%)	.45 (55%)	.25 (75%)	.56 (44%)	.38 (62%)	.56 (44%)	.81 (19%)
WITHOUT CAMERAS	---	---	---	---	---	---	---	---	---

[1] The percentage reduction corresponding to the odds ratio is shown in parentheses.
[2] These are the values that were used to calculate the odds ratios.
--- Indicates that speed and volume data was unavailable as a result of pneumatic tube failure or traffic counter memory loss.

TABLE F-7. ODDS RATIOS[1] AT I-64 EAST SHADWELL

	STATION 1			STATION 2			STATION 3		
	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE	ANY AMOUNT	BY 5 MPH OR MORE	BY 10 MPH OR MORE
ODDS FOR SPEEDING WITH NO CMS[2]	5.16	2.61	1.05	.91	.23	.040	8.91	5.57	2.77
EXCESSIVE SPEED SLOW DOWN WITH CAMERAS	.83 (17%)	.72 (28%)	.64 (36%)	.33 (67%)	.26 (74%)	.16 (84%)	.16 (84%)	.10 (90%)	.08 (92%)
WITHOUT CAMERAS	.61 (39%)	.51 (49%)	.51 (49%)	.29 (71%)	.30 (70%)	.18 (82%)	.18 (82%)	.10 (90%)	.09 (91%)
HIGH SPEED SLOW DOWN WITH CAMERAS	.42 (58%)	.38 (62%)	.37 (63%)	.27 (73%)	.26 (74%)	.16 (84%)	.06 (94%)	.04 (96%)	.04 (96%)
WITHOUT CAMERAS	.49 (51%)	.42 (58%)	.38 (62%)	.26 (74%)	.22 (78%)	.17 (83%)	.11 (89%)	.06 (94%)	.05 (95%)
REDUCE SPEED IN WORK ZONE WITH CAMERAS	.73 (27%)	.69 (31%)	.60 (40%)	.33 (67%)	.25 (75%)	.13 (87%)	.24 (76%)	.16 (84%)	.13 (87%)
WITHOUT CAMERAS	.46 (54%)	.37 (63%)	.30 (70%)	.31 (69%)	.22 (78%)	.18 (82%)	.088 (91%)	.036 (96%)	.023 (98%)
YOU ARE SPEEDING SLOW DOWN WITH CAMERAS	.65 (35%)	.57 (43%)	.37 (63%)	.10 (90%)	.09 (91%)	.04 (96%)	.05 (95%)	.01 (99%)	.01 (99%)
WITHOUT CAMERAS	.34 (66%)	.22 (78%)	.17 (83%)	.14 (86%)	.13 (87%)	.11 (89%)	.036 (96%)	.013 (99%)	.0097 (99%)
SLOW DOWN NOW WITH CAMERAS	.45 (55%)	.34 (66%)	.29 (71%)	.13 (87%)	.09 (91%)	.05 (95%)	.06 (94%)	.02 (98%)	.01 (99%)
WITHOUT CAMERAS	.49 (51%)	.36 (64%)	.31 (69%)	.38 (62%)	.10 (90%)	.10 (90%)	.086 (91%)	.036 (96%)	.017 (98%)

[1] The percentage reduction corresponding to the odds ratio is shown in parentheses.
[2] These are the values that were used to calculate the odds ratios.
--- Indicates that speed and volume data was unavailable as a result of pneumatic tube failure or traffic counter memory loss.