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Activated Advance Warning for Railroad Grade Crossings

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FOREWORD

This report describes a research study performed to:

1. Investigate the use of activated warning devices which would be used in advance of activated railroad grade crossing signals where the sight distance of approaching drivers is restricted;

2. Determine which types of crossings could benefit from the installation of activated advance warning devices;

3. Develop and test prototype activated advance warning devices.

The research was performed by JGM Associates under contract to the Federal Highway Administration (FHWA), Office of Research.

The study findings indicate when activated advance warning signals were used drivers decelerate in the area of the signal, perception and reaction time to the at-crossing signals was reduced, and most drivers did properly interpret the activated advance warning signals. Only limited field testing was undertaken during the study. A more extended field demonstration is planned to positively identify which of the activated advance warning signals is the most effective.

Sufficient copies of this report are being distributed to provide a minimum of one copy to each FHWA regional office, one copy to each FHWA division office, and one copy to each State highway agency. Direct distribution is being made to the Division offices.

Charles F. Scheffey
Director, Office of Research

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16. Abstract
The objectives of this research were to design, develop and test prototype activated advance warning devices (AAWD's) for use in advance of rail-highway crossings with flashing lights or flashing lights and automatic gates and associated train detection circuitry. Other objectives were to establish guidelines for using such devices and to identify the types of crossings where activated advance warning would be most effective.

A literature review and survey of existing AAWD installations led to the development of four candidate devices, all consisting of a primary symbol warning sign, a supplemental message sign and a pair of yellow flashing lights activated by the approach of a train. Indoor laboratory film tests were conducted which focused on subject understanding of the sign components of the devices. Approximately 330 licensed and soon-to-be-licensed drivers took part in the tests, which revealed that an RXR symbol and directional arrow within a diamond sign present a readily understood message, particularly effective when the crossing lies in or beyond a curve ahead. Limited outdoor tests of full-scale devices verified the indoor test results, and gave further information on the effectiveness of the flashing yellow signals.

Three of the four candidate AAWD's were field-tested, with day and night evaluation of vehicle speeds, braking location and driver looking behavior. All three devices proved effective in alerting and preparing the driver for at-crossing signal activation. One of the tested devices is recommended for deployment and guidelines are given for its location, placement and operation. Additional research to supplement the present findings is also recommended.

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1.0 INTRODUCTION

This report describes a two-year study to:

1) Investigate the use of activated warning devices in advance of railroad grade crossings that have activated warning devices at the crossing,

2) Ascertain whether there are certain types of such crossings for which the installation of activated advance warning devices (AAWD's) is especially warranted,

3) Develop several prototype AAWD's and test these devices in the laboratory, and

4) Select and field test at least three of these devices.

1.1 Background

Section 8B-3 of the Manual on Uniform Traffic Control Devices (MUTCD) states that "A Railroad Advance Warning sign shall be used on each roadway in advance of every grade crossing, except on low volume, low speed roadways crossing minor spurs or other tracks which are infrequently used and which are flagged by train crews, in the business districts of large cities where active grade crossing traffic control devices are in use, or where physical conditions do not permit even a practically effective display of the sign (1)*. Since Railroad Advance Warning signs are usually located off the railroad right-of-way, they are the responsibility of the public authorities. No mention is made by the MUTCD of the use of different advance warning devices for activated versus passive crossings although two studies emphasize their need, Schoppert and Hoyt(2) and Wilde, et al. (3), while recommendation for a change in advance signing for passive crossings evolved from the conduct of a third study, Koziol and Mengert (4). There is also no mention in the MUTCD of advance warning signals for crossings of any type, although use of an active device such as a hazard warning beacon falls within the guidelines established by the MUTCD. (For the purposes of this report an active device or signal is one that is always operating, while an activated device is one that uses train detection circuitry for activation and is therefore operational only when a train is present.) There are a number of crossings throughout the country for which flashing yellow signals, hazard identification beacons, have been attached to the standard advance warning sign. Other devices have also been devised and installed as well (see Section 4.0), some of which have been tied into the crossing signal circuitry for activation only upon the approach of a train, while others are always active. Some of these devices have been installed on a trial basis, while others are considered more permanent. Except for the supplemental hazard identification beacons, none of the devices has been approved for this use by the MUTCD. Many jurisdictions throughout the U.S. have taken steps to provide specialized advance warning for crossings and demonstrate a growing awareness that there are certain types of crossings for which the standard advance warning sign, with or without the hazard identification beacon, does not provide the motorist with adequate warning information.

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*Numbers in parentheses refer to references given at the end of the report.

Contributing to this awareness is the fact that while approximately 22 percent of public grade crossings have activated devices, these crossings still account for about 47 percent of all train-involved grade crossing accidents. While this disproportion of accidents may be partially explainable by higher train and vehicle volumes, it is still clear that a desirable safety level has not yet been achieved, and that the total warning system at crossings must be investigated to ensure that motorists are more adequately warned of the potential hazards at grade crossings. Previous research (5) has dealt with the at-crossing aspect of the system; the present project deals with the advance warning aspect, and is specifically restricted to activated advance warning for crossings having activated at-crossing signals. While the subject of active advance warning is not ignored, it is felt to be a concept more applicable to crossings with passive warning devices.

1.2 Summary of Results

This section summarizes study accomplishments, including a review of the relevant literature, a survey of existing installations of activated advance warning devices (AAWD's), an accident survey, selection of a candidate set of AAWD's, indoor and outdoor laboratory evaluations of these AAWD's and, finally, field tests of the most promising devices.

1.2.1 Literature Survey

A synthesis of the literature survey is contained in Section 3 of this report. A detailed annotated bibliography appears as Appendix A to the interim project report (6). Collectively, all referenced material has had impact on the researchers' conduct of the project; however, some of the reported research was considered to be especially significant, including:

1) Schoppert and Hoyt (2) -- This was the first truly comprehensive study of grade crossing safety, and provided the basis for a number of subsequent research projects.

2) Pollock and McDole (7) -- This report on motorist familiarity with signs strongly influenced the researchers' choice of signing and signing symbols to be used in candidate AAWD's.

3) Jacobs, et al., (8) -- This research into the visibility of alphabetic and symbolic traffic signs led the researchers to use a flattened or asymmetric crossbuck or crossing symbol in two of the four candidate signs (see Section 5).

4) Burg and Hulbert (9) -- This paper describes motion picture and slide film techniques used in the evaluation of highway sign effectiveness. These techniques were modified for the present project and used in indoor laboratory tests to measure subject understanding of the candidate signs.

5) Forbes, et al., (10) --This research on letter and sign contrasts and brightness had major influence on the development of

a candidate sign (primary sign D, Section 5) devised to give the approaching driver maximum target value against both light and dark sign backgrounds.

1.2.2 Survey of Existing AAWD Installations

To supplement documented information on past or present AAWD installations, primarily Butcher (11), the researchers contacted knowledgeable public agency officials throughout the U.S. Based on the information thus obtained, Section 4 describes a cross section of typical AAWD installations presently on our highways. The complexity of these devices ranges from a single train-activated yellow signal attached to the standard advance warning sign, MUTCD-specified W10-1, to an elaborate device employed in advance of a rail/freeway crossing.

Of particular interest was the information obtained concerning the crossing anomalies (terrain, roadway geometry, driver distractions, reduced visibility conditions, etc.) which formed the basis for decisions to use activated warning devices in advance of the railroad crossing. With few exceptions, there is a common element that underlies the majority of these installations, i.e., they are all characterized by conditions, permanent or intermittent, such that the crossing signals do not warn the driver of the presence of a train far enough in advance of the crossing.

1.2.3 Accident Analysis

The researchers reviewed available grade crossing accident-inventory data, including the 1975 matched DOT-AAR inventory records and the FRA incident records, in an effort to determine those types of activated crossings for which AAWD's would be advantageous. Unfortunately, it was found that the type of information required, namely, approach roadway characteristics, line of sight constraints, etc., is not typically included in accident or inventory records.

Schoppert and Hoyt (2) concluded that accident data should not be the sole basis upon which decisions are made to provide activated warnings at railroad grade crossings. It appears that as currently structured, accident data also cannot provide guidance in deciding upon the employment of AAWD's.

1.2.4. Selection of Candidate Devices

The research concentrated on development of a simple, not-too-expensive device that would meet several criteria, including high conspicuity, a readily-understood and unambiguous message (even in the fail-safe mode), and general conformance with existing signing practices. The result was selection of a design for the AAWD consisting of three components: a primary symbol sign, a supplemental message plate, and a pair of alternately flashing yellow signals. Consideration was also given to a variable-message supplemental plate that would present two different messages -- one for the activated state and one for the passive state. A detailed discussion of the candidate devices is contained in Section 5.

The rationale for development of the primary sign candidates of the AAWD was based upon past research as well as current practices and standards. A set of three new signs was chosen for evaluation along with the standard W10-1. In addition to the RXR warning symbol, the content of the new signs included directional arrows intended to focus the driver's attention toward the crossing location which may be hidden or lie outside his direct view of the roadway ahead. The supplemental message plate was intended to provide the motorist with useful information not otherwise contained in the AAWD, and the flashing lights provided a highly-conspicuous activation component.

1.2.5 Laboratory Tests

Candidate AAWD's were evaluated in both indoor and outdoor laboratory tests, described in Sections 6 and 7, respectively. Indoor laboratory test subjects included 36 licensed drivers and 297 driver education students. Evaluation of the two groups showed their understanding of traffic control devices to be roughly equivalent. Outdoor laboratory testing utilized 17 licensed drivers as subjects.

Understanding of the four primary sign candidates, each employing a variation of the familiar "RXR" symbol plus directional arrows, was the major thrust of the indoor laboratory tests using a set of 16mm motion picture films. Both subject groups exhibited roughly 90 percent or better understanding of the railroad crossing message of all candidate signs.

Nearly 80 percent of the subjects understood the intended meaning of a curve arrow (W1-2) within the primary sign to signify that the crossing was "around the curve" in the roadway ahead. A vertical arrow, intended to communicate the message "railroad crossing over the hill ahead" (vertical sight distance obstruction) failed to achieve a significant degree of subject understanding.

A turn arrow within the primary sign was used to indicate an intersection turn ahead, beyond which is the railroad crossing. This use of the W1-1 arrow elicited a subject understanding level of nearly 75 percent. Using a slide presentation technique, the driver subjects, as well as a small group of the student drivers, were also asked to express their preferences with regard to the primary signs, the use of arrows within the primary signs, and supplemental messages. In their recommendation for the AAWD's to be field tested, the researchers gave consideration to the subjects' preferences.

Also contained within Sections 6 and 7 are data on driver response to the primary signs, arrows, supplemental messages and activated flashing signals when viewed in a dynamic real-world setting. The results of this "outdoor laboratory" testing indicated that roughly one-half of the subject drivers (9 of 17) guessed the correct meaning of the flashing lights (together with the primary sign) without an explicit supplemental message. Legibility distance for the supplemental message plates was about what had been expected, with visual acuity being the major factor underlying observed differences. A secondary factor was the length of the message, which was varied from two to four words. Results were inconclusive relative to message length versus perception distance. Driver understanding of arrows was about the same as indicated by the film tests, although the intended meaning of the turn arrow was not understood as well as expected. One candidate primary sign stood out as being the best in terms of maximum recognition distance potential for a given set of sign dimensions, under all lighting conditions.

1.2.6 Field Tests

Three sites were selected for limited field testing. Each field site represented one of three fundamental conditions under which an AAWD would be employed to provide safe stopping sight distance. These three fundamental conditions are:

1) Physical obstructions to sight distance, either permanent or intermittent, such that when the railroad signals come into the driver's view, there is insufficient distance to the crossing to permit adequate perception and reaction time (distance) plus braking distance to bring a vehicle to a stop at a crossing.

2) An approach roadway geometry such that the driver is not alerted by crossing signals until he is too close to the crossing to perceive, react and stop his vehicle.

3) An approach roadway, e.g., downgrade, which produces extended braking distances such that the crossing falls into fundamental situations 1 or 2 above.

The three devices tested differed only in the primary sign component of the AAWD, with each device employing:

1) Vertically-positioned, alternately flashing yellow signal heads which were activated prior to the railroad crossing signals and

2) A fixed supplemental message plate bearing the three word message WATCH FOR TRAINS.

Summary results were as follows:

- Activation of the AAWD produced both vehicular deceleration in the zone contiguous to its location and decreased driver perception and reaction time to crossing signal activation. Perception and reaction to crossing signals was definitely more of a problem during the day than at night at those sites tested.

- Novelty effects of AAWD installation were clearly evident at one site, and were seen to wear off over a four week period. More permanent driver behavior modification brought about by the device would require more extensive testing and therefore could not be evaluated due to limited time and budget constraints.

- Erratic driver behavior and questionable braking performance by large trucks posed a considerable problem for the researchers whenever endeavoring to safely measure driver response to manually-activated signals. The increasing proportion of large trucks in the traffic flow suggests the need to reevaluate the appropriateness of classical braking distance data as the basis for locating traffic control devices in advance of a hazard.

- Driver non-compliance with the mandatory stop required at flashing railroad signals was much greater than expected. Many slow run-throughs were noted but of greater concern was the frequency of high-speed violators of the law. The frequency of running beneath lowering gates was also higher than expected, with numerous "close calls," including seven instances when the gates had to be raised in an effort to avoid what appeared to be a likely collision.

1.2.7 Development of Guidelines

Section 9 of this document includes recommendations for location and placement of the AAWD that endeavor to incorporate recent developments in signing practice. Also included in Section 9 is a framework for determining whether a particular crossing location would warrant AAWD installation. To discourage over-use of an effective device, and to avoid adding more unneeded clutter to the roadside, several specific examples of crossings are given that do not require "extension of the effective distance" of the crossing-located signals.

2.0 CONCLUSIONS AND RECOMMENDATIONS

Conclusions that the researchers feel are clearly supported by the study findings are summarized in Section 2.1, together with a brief discussion of project results supporting these conclusions. Section 2.2, Research Implications, presents conclusions which the researchers feel are implied by the data, together with other research findings. Section 2.3, Research Considerations, contains the recommendations as to areas in need of further research, based upon the researchers' opinion that data produced by such research would improve the final product of the present effort.

2.1 Research Conclusions

The general conclusions listed below have been drawn from conduct of this research project.

- A single pair of activated yellow warning signals is sufficient to draw the driver's attention to the other information contained in the Activated Advance Warning Device (AAWD) as well as alert him further in advance, thereby allowing him more time to perceive and react to activated railroad crossing signals (Section 8.5).

  The conspicuity of a pair of flashing signals has been well demonstrated (5) and their use established in practice (Section 4). Eight-inch heads were used in the field tests and are adequate for installations without nighttime background competition (5). Increased signal conspicuity can be gained by increasing head size and/or flash rate (Section 3) if needed. Further increases in conspicuity can be gained through the use of xenon flashlamps and irregular flash patterns (5). The choice of 2 yellow signals rather than one is based upon redundancy considerations as well as on providing a stimulus uniquely different from the single hazard warning beacon commonly found on highways.

- The integration of a railroad warning symbol, RXR, and a curve arrow into a diamond sign is properly interpreted to mean "railroad crossing in a roadway curve ahead" by most drivers on first exposure to this novel sign (Sections 3.6, 6.3 and 7.4).

  Both preliminary (informal) tests in the present study and prior research results indicate that an X symbol of varying shape (and color) when spanned by two R's is easily recognizable as to meaning. Subject understanding of the integrated message presented by the curve arrow and RXR symbol was nearly 79% among those subjects who viewed the 16mm films (Section 6.1.3). This indicates that complex messages, too lengthy for word display, show promise for effective message communication through usage of familiar symbols.

2.2 Research Implications

Listed below are conclusions reached both during and following the completion of various project tasks that are implied by the research findings, rather than clearly supported by them. Formulization of these conclusions has been based upon data collected during the research, insights gained in conducting the study, allied research results and the expertise of the research staff.

1) The WATCH FOR TRAINS is considered the best non-changeable, supplemental message of those studied.

   The WATCH FOR TRAINS message was the second choice of test subjects in the laboratory tests. These subjects' first choice was RAILROAD XING AHEAD, a message which adds little supplementary information to that contained in the primary crossing warning sign. Cost effectiveness considerations in displaying a supplemental message containing little (if any) additional information was not a constraint imposed on subjects in making their selections (Section 8.1).

2) Of those studied, the supplemental word message TRAIN WHEN FLASHING is best for displaying when the AAWD is activated, provided it can be made "fail-safe."

   This message was the laboratory test subjects' choice for a sign message to be displayed when the AAWD is operating, i.e., a train is at or near the crossing (Section 6.2). It provides redundancy (TRAIN) as well as the meaning of the flashing lights (WHEN FLASHING). Due to potential liability problems, it cannot be recommended as the legend in a fixed (non-changeable) message plate.

   While use of a changeable message sign that displays TRAIN WHEN FLASHING when the AAWD is activated and WATCH FOR TRAINS when the device is inactivated is desirable, it cannot be recommended as a requirement due to its cost and the fact that it is not necessary at all site installations. The changeable message approach, however, should be given strong consideration at those sites where there are physical obstructions which limit the drivers' viewing distance of the railroad crossing. In such instances a doubtful driver, upon clearing the obstruction, may be committed to "running the signals" or taking some alternative, undesirable action to avoid colliding with a train. The changeable message will aid the driver in clearing up any doubts he may have pertaining to what lies beyond the sight distance limiting obstruction.

3) The curve arrow component of the primary advance warning sign is an essential element of the AAWD, where warranted (curving approach roadways), in that it will provide a meaningful sign having a high level of driver credibility.

   Subject understanding of the curve arrow was good, and post-test discussions with subjects revealed a very strong preference for this type of signing. It is therefore strongly recommended that the curve arrow (right or left) be made an integral part of the primary sign at those installations having curving approach roadways.

4) The primary crossing warning sign recommended is designated as Primary Sign B (Figure 14) in this study.

Recommendation of Primary Sign B is based on a number of factors:

a) The researchers' conclusions that a curve arrow, where warranted, is an essential component of the Primary Sign (thus excluding the MUTCD standard W10-1, whose design does not make feasible incorporation of a curve arrow within the sign proper).

b) Primary Sign B seems to offer the best combination of other elements felt desirable in an advance warning sign, such as diamond shape (which also excludes the W10-1), flattened "X" and the color red, without exhibiting some of the drawbacks of the other primary signs tested.

Regarding use of the color red in Primary Sign B, it is recognized by the researchers that not only is red a color having high target value but also, if over-employed, it may well lose its driver impact. Signs which incorporated the color red are few in number and imply serious consequences if their messages are unheeded. This type of driver message appears appropriate for a railroad crossing.

The precedent for use of the color red at railroad crossings has been established through:

1) The use of red and white striped railroad gate arms,

2) A proposed change in the Canadian Railroad Crossbuck to one that is white with a red border, and

3) A recent recommendation for new signing in advance of grade crossings with passive devices.

5) The standard AAWD recommended for consideration as a result of this research should at a minimum consist of:

a) A pair of vertically-positioned (for side of road, post-mounted installations) alternating yellow flashing 110V AC-powered signal heads, and

b) A primary crossing warning sign, pole-positioned between the two signal heads.

c) A supplemental fixed message plate stating WATCH FOR TRAINS, pole-mounted directly below the primary sign.

The rationale for the vertical positioning of the two yellow signals as tested at all three field sites is discussed in Section 5.4. The recommendation for 110 V AC power is based upon providing the signal with sufficient luminance for it to be seen by drivers in bright daylight conditions (low contrast). Provision of standby battery power backup (with DC to AC conversion) and its associated increased costs is not warranted, based upon the recommended sign configuration, which is fail-safe. Consideration should be given to dimming extremely bright yellow signals at night, as they may provide a glare source and make it difficult for the driver to see the warning sign.

6) The minimum size of the AAWD signs should be based upon the following requirements:

a) Minimum legibility distance (rural roadway) of 250 feet (76 m) for the WATCH FOR TRAINS message. (For drivers with 20/23 visual acuity, this roughly corresponds to a 5 inch (12.7 cm) letter height.)

b) A size differential between the Primary Sign and Supplemental Message Plate which clearly implies to the driver that the Primary Sign contains primary information and the supplemental plate (smaller in size) contains secondary information.

The Primary Signs tested during conduct of the project were 48 inches (1.2 m) in size while the supplemental message plates were 3 x 2 feet (.9 x .6 m). This was considered reasonable proportional scaling in the two sign sizes. No attempt was made to decrease the message plate dimensions while maintaining a 5-inch (12.7 cm) letter size; however, it is reasonable to expect this can be done without decreasing the legibility distance of the word message. The resulting size decrease in the message plate would allow comparative size decreases in the Primary Sign while maintaining roughly the same relative proportion of the two signs. In the development of guidelines (Section 9), particular care was taken to specify where AAWD installation would be warranted. Adherence to the guidelines would mean that installation would occur only where needed. This restricted usage, plus the use of an RXR symbol and possibly a curve arrow within the Primary Sign, would seem to dictate a minimum size for the Primary Sign of roughly 42 inches (1.1 m). This size seems a reasonable compromise between the standard warning sign of 36 inches (0.9 m) and the "Texas Sign" (Section 4.2.8), which is 48 inches (1.2 m).

7) To maximize effectiveness of the AAWD as a traffic control device it is recommended that activation (and de-activation) of the yellow signals should not be concurrent with activation (and de-activation) of the at-crossing signals.

The AAWD should activate prior to the flashing of the railroad crossing signals. In this manner, AAWD operation can provide a crossing clearance interval for those vehicles located between the AAWD position and the railroad crossing when the train is detected by the track circuitry. In addition, the method of terminating activation of the AAWD must be resolved on a site-by-site basis, with special attention given to providing sufficient time to clear stopped vehicles following de-activation of the railroad signals. This method of operation may well require modifications to the train detection circuitry (Section 9).

2.3 Future Research Considerations

It is recommended that the following research be conducted to supplement and complement the findings of the present study:

1) Conduct field tests with improved (new) railroad crossing signal displays, with emphasis upon driver understanding of the meaning of the various stages of railroad signal displays. Furthermore, such railroad signal displays should be more in conformance with other traffic control signal displays encountered in the roadway scene.

   This recommendation is based upon the following considerations:

   a) There is at present no indication to the vehicle driver that he has right-of-way when the signals are inactive, e.g., a green signal,

   b) There is at present no warning to the driver that his vehicular right-of-way is about to be removed by an oncoming train, e.g., a yellow signal, and

   c) There is no clearance interval display for vehicular traffic. It is recognized that current practice in railroad signal operation attempts to overcome some of the foregoing deficiencies by providing, for example, a minimum interval of 20 - 25 seconds between signal onset and train arrival at the crossing and varying delay times between signal onset and downward railroad gate movement; however, these are subtleties, and probably not widely understood.

2) Develop reasonable estimates of large truck braking distances at highway operational speeds. These are needed to accurately describe safe stopping sight distance where these vehicles operate. Under-estimates of truck braking distances would negate the projected safety benefits arising from AAWD installations (Sections 8.5 and 9).

3) The researchers' recommendation that Primary Sign B be used as part of the AAWD configuration was based primarily on the laboratory phase of the project. Limited field testing together with radar data collection difficulties and site differences precluded evaluation of the relative effectiveness of the primary signs tested in the field (although all devices were shown to be effective).

   Despite this, the researchers feel that their recommendation of Primary Sign B is justified. It is possible, however, that in order for such a recommendation to gain acceptance, additional field tests might be warranted before any new warning sign would be considered for use instead of the existing standard (W10-1) as the primary warning sign component of the AAWD. Should such further testing be needed, the following suggestions are made regarding how such tests might be conducted.

The fact that the proposed new warning sign and applicable curve arrow is understood and desired by subjects has already been established by the laboratory tests, as well as the fact that the recommended sign and curve arrow carries far more driver information (with simple symbolic content) than the existing W10-1. It is the researchers' contention that further verification of this fact is best conducted in the laboratory, since normal field-collected data do not supply this type of information unless an extensive driver survey is also conducted.

It should also be pointed out that the activated signals will dominate driver speed response and obliterate any speed differences that would otherwise be attributed to the primary signs. It is therefore recommended that if additional field testing is conducted, it should focus on the AAWD when it is inactivated. If comparison is made between the W10-1 and the recommended primary sign, it should be made using multiple sites and both signs (first one, then the other) at each site, balancing the order (first and second) over the sites.

Driver looking behavior (at the AAWD) and speed profiles in the vicinity of the AAWD (between 400 - 500 feet (122 - 152 m) in advance of and 100 - 200 feet (30 - 61 m) after the AAWD location) appear to be the most promising MOE's for this comparison. Location of the AAWD in a curve, centered in the driver's cone of vision, appears to be the optimal placement for observing maximal driver response changes and, hence, for providing the kind of data necessary to make the desired comparison. Furthermore, if the principal data will be collected when the device is inactive, then the question arises as to whether it is even necessary to have non-flashing lights present. Evaluation of the primary signs and message plates without the lights would cost considerably less than it would with the lights.

3.0 LITERATURE SYNTHESIS

One purpose of the research undertaken was to determine whether the use of activated advance warning devices would provide increased safety for motorists at railroad crossings employing activated warning devices. As part of this study, an extensive survey of relevant literature was carried out. The following subsections present a synthesis of the information from the literature review that is deemed most relevant to the project. The information is organized under a number of headings, each representing a relatively distinct subject area.

3.1 Rationale for an Activated Advance Warning Device

Schoppert and Hoyt (2) discuss the differing circumstances facing a motorist at a crossing with activated warning devices as opposed to passive devices. Aside from the fact that the activated crossing may have different characteristics than a passive crossing (higher train and/or highway volumes, more tracks, poorer sight distance, etc.), a different pattern of driver actions should occur at a crossing. For example, a passive crossing places full responsibility upon the motorist for looking and listening for a train, as well as for making any changes in his speed or path. An activated crossing (without gates), conversely, requires the motorist to perceive the warning signals and when they are in operation, to stop and not proceed until it is safe to do so. When gates are present, a positive barrier will be in the driver's path, whether or not a train is physically present.

Thus, each type of crossing produces a distinct set of driver expectations with regard to anticipated searching and deliberation behavior. Schoppert and Hoyt argue that this difference requires different advance warning treatments for the two types of crossings, and they make general recommendations as to how the advance warnings for activated crossings should be distinctive in message content. (They further suggest the possibility of supplementing this distinctive message with pavement rumble strips and activated lights and/or bells, to provide bi-modal redundancy.)

Wilde, et al., (3) studied driver behavior on the approaches to several activated crossings in relation to activity at the crossings themselves. They found a high degree of non-uniformity in motorist behavior in approaching and traversing the crossings when the signals were not activated. Variability in both speed and visual search patterns was extreme at each crossing, and varied from crossing to crossing. In addition, the study revealed marked differences in required driver behavior at the different crossings in their activated state, due to the fact that warning times varied widely, as did waiting time at the crossing and crossing occupancy time. Also, a surprisingly high incidence of "false alarms" (that is, false signal activations) was found. To improve this situation, Wilde, et al., recommend a reliable (i.e., credible) system that provides a constant and standardized warning time, and an activated advance warning device (AAWD) that is activated before the crossing signal. They recommend the AAWD to be distinctive in appearance, with a fail-safe indication, and to be so placed that motorists would have ample time to stop (after its activation) before reaching the crossing, or ample time to cross the tracks before activation of the crossing signals if the AAWD activates <u>after</u> they have passed it, taking into account the prevailing speeds or posted speed limit, whichever is higher.

Michael (12) reports the results of an American Railway Engineering Association study which recommends development of new advance warning signs and sign location criteria, but is not specific to activated crossings.

3.2 Experimental Installations of AAWD's

Section 4 of this report contains a discussion of AAWD's currently undergoing evaluation by several states utilizing experimental installations. For the most part, these current activities have not yet been documented in formal publications. Butcher (11) provides a review of advance warning devices that had been investigated to 1973. Among the devices discussed are flashing lights, both yellow and red, in advance of the crossing, and used both separately or in conjunction with the standard advance warning sign (W10-1); however, no evaluation of the effectiveness of these devices is given. Another device reported by Butcher was located 800 feet (244m) in advance of the crossing and involved a flashing yellow light and neon sign displaying "RXR" over the word "GATE". The entire device was activated simultaneously with the crossing signals and, according to Butcher, led to a significant reduction in collisions with the gates. Butcher also describes a cantilevered sign 500 feet (152m) before the crossing that displayed a flashing "RR SIGNALS AHEAD" message five seconds before the crossing signals were activated; however, no evaluation of the effectiveness of the device is given. Butcher also describes the Texas System, which is discussed in the next section.

Butcher discusses some proposed AAWD's, including an illuminated "STOP AHEAD" sign with 6-inch (15cm) red letters, placed with the standard advance warning sign and activated in advance of the crossing signals. Also proposed was a cantilevered variable-message sign displaying a continuously-lighted "TRACKS AHEAD" message when non-activated and a flashing red message (e.g., "TRACKS BLOCKED, STOP AHEAD") when activated.

It is clear from Butcher's review, as well as from evaluation of a variety of current experimental devices, that there is no uniform approach to the design of AAWD's. The devices tried or proposed varied widely in terms of message content, placement, activation sequence, and conspicuity aids,e.g., flashing lights. The effectiveness of the devices was not measured. This is no doubt due to the difficulty of specifying appropriate measures of effectiveness (MOE's) and the costs associated with acquiring the large volume of data requisite to arriving at statistically significant results.

3.3 Techniques for Evaluating Devices

A number of studies have been conducted which were primarily concerned with the effect on motorist behavior of various traffic control devices, including grade crossing devices. Some of the techniques used in these studies show promise for evaluating AAWD's as well.

Field testing of experimental traffic control devices can be an expensive and time-consuming process. If a large number of candidate devices are involved, valid field testing becomes almost impossible to accomplish within practical time and budget constraints. Therefore, "pre-testing" of candidate devices in a laboratory setting (either indoors or outdoors) has been recommended as an economical means for screening candidate devices in advance of field testing. Hulbert and Burg (13) and Burg and Hulbert (9) describe film techniques (both motion picture and slide) used to study driver reaction to various signing configurations in the laboratory. A modification of these techniques was used in the present study to reduce the number of candidate AAWD's to a manageable few for field testing.

Forbes, Fry, Joyce and Pain (10) also utilized an indoor laboratory film technique to evaluate sign characteristics, and Roberts, et al. (14) evaluated the message content (printed and symbolic) of traffic signs utilizing tachistoscopic presentation of slides. Forbes, Pain, Joyce and Fry (15) used both an indoor film technique and an "outdoor laboratory" technique involving observations of signs from a moving vehicle. This last technique was utilized (in modified form) in the outdoor laboratory phase of the present study.

A number of studies have involved field testing of various traffic control devices, and these studies are of interest because of the measures of effectiveness (MOE's) used to evaluate these devices. The most common MOE used has been speed, or speed change, both approaching and passing the device in question. Butcher (11) and Russell (16) both studied driver reaction to standard and modified crossing signals by means of a photographic data collection system to determine vehicle speed profiles approaching a grade crossing. Wilde, et al., (3) also used approach speeds and speed change profiles in their study of "normal" driver behavior approaching six unmodified crossings with activated signals. Driver looking behavior also was recorded. The major finding was the great variability in driver performance, with regard to both speed and looking behavior.

Dommasch, et al., (17) used spot speeds at the crossing as well as driver interviews to determine the effects, if any, of utilizing new advance and at-crossing signs for passive crossings. Goldblatt (18,19) studied continuously-flashing beacons and vehicle-activated flashing beacons at intersections and in other applications, using approach speed as a major criterion of driver performance. He also considered traffic conflicts, brake-light onset and gap acceptance. Included in the study was an advance warning device upstream of the intersection at which the flashing beacon was installed. The AAWD had a yellow beacon and a sign which bore the message "WHEN FLASHING - VEHICLE CROSSING", and both standard (black on yellow) and non-standard (black and red on silver) color combinations were evaluated. All beacons (advance and at the intersection) were activated by the vehicle on the cross (minor) street. Another activated advance warning that was studied consisted of a 12-inch (30cm) activated yellow beacon mounted above a standard "STOP AHEAD" advance warning sign. The most consistent finding from the series of experiments conducted by Goldblatt was that both speed variance and mean approach speed declined with the AAWD's in operation. The latter measure was especially notable for the faster drivers.

Hanscom (20) recorded approach speed and motorist observations at critical locations in advance of icy bridges, with combinations of activated and non-activated signs both "at" the bridge (i.e., 150 feet {46m} in advance) and 1000 feet (305m) in advance of the bridge. Activated signing resulted in lowered approach speeds and was more effective at night, when the hazard (icy bridge) was greater than daytime and on short-distance approaches where the bridge did not compete visually for driver attention. The activated signs, both at the bridge and in advance, were turned on manually when there was ice <u>or a danger of ice</u>; therefore, they were sometimes on when no ice was present, probably reducing their credibility somewhat. The AAWD's consisted of 36-inch (91cm) diamond-shaped black on yellow signs, one saying "BRIDGE ICY AHEAD" (with "ICY" in steady burn red letters when activated) and the other "ICE ON BRIDGE", with a "WHEN FLASHING" plate below the sign along with two 8-inch (20cm) yellow flashers.

In a study of signing to warn of wet weather skidding hazards on curves, Hanscom (21) measured vehicle speed, headway, mean acceleration or deceleration, plus driver observations of the signing. He used the "Slippery When Wet" symbol sign by itself, and also with supplementary aids to increase its specificity and conspicuity, i.e., continuously-flashing lights and an advisory speed limit. The use of flashing lights was shown to produce a significant decrease in approach and passage speed, which was not produced without flashing lights. The "novelty effect" was not studied. The author recommended that activation of the beacons be linked to the onset of rainfall, to improve credibility.

Hanscom and Berger (22) used mean speed, headway, and vehicle behaviors (e.g., erratic maneuvers) to study the relationship between guide signing at freeway interchanges and motorist actions. Signing that presented the driver with a more difficult information-processing task led to more high-risk gore weaves, driving slowly, and lane changes. This finding, of course, has relevance to the message content of <u>any</u> sign, including AAWD's.

Sanders, et al., (23) determined that driver looking behavior and speed were valid means for evaluating the effectiveness of countermeasure devices at or in advance of grade crossings. The AAWD's tested consisted of the standard W10-1 advance sign with a pair of either low- or high-intensity 6-inch (15cm) flashing yellow lights attached to it. The authors concluded that the flashing lights resulted in increased driver looking behavior, speed decreases and increased driver stops at the crossing. The higher intensity lights were more effective than the lower intensity lights.

Hostetter (24) summarizes a lengthy study of color and shape coding for freeway route guidance signing at problem interchanges, using traffic conflicts and driver uncertainty as MOE's. The most critical finding for the present project was that the addition of informational elements to existing signing can reduce driver uncertainty. This is relevant to the present project's consideration of arrows and supplemental message plates for crossing AAWD's.

Finally, the longest-range MOE that can be used to evaluate the effectiveness of warning devices (or any change in the highway system made for safety reasons) is the before-and-after comparison of accident experience. Hammer and Tamburri (25) used this approach to study the effectiveness of flashing beacons both at the point of conflict (non-signalized intersections and passive crossings), and in advance of the hazard (curves, intersections and school zones). The results generally pointed toward a reduction in both the frequency and severity of accidents as a direct result of using (continuously flashing) beacons (yellow except for those at RR crossings, which were red). Also, 12-inch (30cm) flashers proved more effective than 8-inch (20cm) flashers. Another before-after accident survey was conducted by Schulte (26), and dealt with the changeover of a large number of crossings in California from passive to activated (at-crossing) warning systems. As would be expected, an improvement in the safety picture was shown.

3.4 Conspicuity and Legibility of Signs

In view of the fact that an AAWD for crossings is likely to involve symbols and/or lettering to convey a message to the motorist, some of the extensive research that has been conducted on the legibility and conspicuity of signing was reviewed. Forbes (27) summarizes research showing that brightness contrast is a prime determinant of the "target value" (visibility) of highway signs, with color contrast of lesser significance. Contrast of the sign with its environmental background is important for "total sign visibility" and contrast between the sign message and sign background is important for sign legiblity. Sign size is important for visibility, especially when several signs are viewed at once. Signs placed over the roadway get more attention than shoulder-mounted signs.

A study by Forbes, Fry, Joyce and Pain (10) recommends dark signs for contrast with a bright sky or other bright backgrounds. They further recommend light signs for contrast against dark backgrounds. They also found that bright letters or symbols are more legible than dark ones and, therefore, suggest their use on dark signs. Such a sign would possess both bright and dark areas and thus provide contrast against all types of environmental backgrounds.

Jacobs, et al., (8) conducted a laboratory study of sign visibility using both lettered and symbolic road signs, and found symbol signs to have greater legibility distance (due, in part, to their greater stroke width). However, these results are based on resolution distance, and written sign messages often contain familiar phrases and/or redundancy that enhances their legibility distances. Also, the alphabetic version of a sign may be so distinctive that its legibility is as good as its symbolic counterpart. It was also found that sign borders had no influence on legibility and that the flattened crossing symbol  resisted blur better than the symmetric crossroad sign . The authors conclude that signs should be designed for drivers with 20/40 to 20/60 visual acuity, since the number of drivers in that category is too high to be overlooked.

3.5 Research on Flashing Lights and Devices

A number of studies have been conducted that suggest the value of flashing lights or devices in calling a motorist's attention to a particular message or hazard. Already discussed are the studies by Sanders, et al., (23), Russell (16), Hammer and Tamburri (25) and Goldblatt (18,19).

One of the most extensive studies of flashing lights is reported by Ruden, et al., (5). This study was directed at improving the attention-gaining aspect of activated crossing warning devices, and involved both indoor and outdoor laboratory research, as well as a field evaluation. Subject response to a variety of flashing light displays was studied extensively to determine the effects of color, flash rate, brightness, size and placement under daylight, darkness and daytime fog conditions. The results were used in the development of two improved devices which were subsequently field-tested at actual grade crossings.

Briefly summarized, the major findings of this complex study show that:

1) Generally, blue lights are more conspicuous at night, red lights are best in the daytime and orange lights are good in daytime fog. (White lights are best from a conspicuity standpoint, for a given amount of electrical energy expenditure.)

2) Flash rates of 70-90 cycles per minute for incandescent-powered lights are best for gaining attention. For xenon strobe lamps, conspicuity increases with increased flash rate (up to a combined flash rate for a three-strobe unit of 480 flashes per minute), with <u>irregular</u> flash patterns being best.

3) At locations where background competition is present, increasing the size of the flashing light from 8-inch (20cm) to 12-inch (30cm) diameter shows more promise for increasing conspicuity than does increasing the intensity of the light source.

4) Cantilevered and right shoulder-mounted placements are more conspicuous than a left shoulder-mounted location.

5) Gate-mounted red, white, and blue low-powered strobes significantly added to gate arm conspicuity under medium and high contrast conditions.

In a study comparing 12-inch (30cm) railroad signal heads of differing design, Ruden and Hulbert (28) found that there is little correlation between the photometric brightness and subjective appearance, brightness and size characteristics of the lights. This is primarily due to the fact that the 12-inch (30cm) railroad signal typically presents a non-uniform brightness target to the observer, because of "hot spots" on the lens surface. The authors also found that there are random optical distortions in these lights. In addition, the standard lens produces a beam that is horizontally broad and vertically narrow. The distortions described, the "hot spots" and the beam characteristics make proper aiming of these signal lights extremely difficult. The importance of this research for the present study is that it points out that the design constraints of presently used signal heads stems primarily from the usage of low voltage (and wattage) bulbs, which rely on fail-safe battery backup in case of commercial power failures. If this constraint is imposed on flashing lights that may be incorporated in AAWD's, the same difficulty in optimizing their effectiveness is anticipated. Hopkins and Hazel (29) feel that this fail-safe requirement has, in fact, stifled development of more effective (and cost-effective) systems.

3.6 Other Factors to be Considered in Developing AAWD's

A variety of other issues, relevant to the development of effective AAWD's, have been the subject of research in addition to the factors already discussed.

Another factor to be considered is the "design driver" concept which refers to the perceptual and response capabilities to be assumed on the part of the "target" group of motorists for whom the AAWD is being developed. Hulbert and Burg (13) point out the wide range of motorist performance that can be expected, and Wilde, et al., (3) also found extreme variability in driver performance in their study. Both inter- and intra-individual variability have been shown to greatly influence the specificity with which research results can be stated. Clearly, the target or design driver cannot be represented by the "average" performance in this range, but must be toward the poor end of the performance scale.

As indicated earlier, Jacobs, et al., (8) point out the need to design for drivers with 20/40 to 20/60 acuity, and Johnston, et al., (30) review the visual characteristics of the "real" observer and make it clearly evident that significant segments of the driving population cannot perform visually to the standards demanded of them by designers of the highway system.

In addition to the above perceptual factors, there are psychological factors that have to be considered. For example, both Wilde, et al., (3) and Hopkins and Hazel (29) emphasize the need for reliability in any system so that credibility will be established in the minds of the motorists. This means false activations should be rare, or non-existent, and waiting time (at the crossing) should be minimized. Decisional uncertainty should be reduced to a minimum in the system, by correct placement of the AAWD, and by providing a constant and standardized warning time, to avoid creating a "dilemma zone" for motorists.

Hopkins and Hazel emphasize the need for conspicuity of any device, and also for clarity of message, a requirement also emphasized by Hanscom and Berger (22). Hopkins and Hazel also indicate the desirability of incorporating the grade crossing warning system into the overall system of highway traffic control devices, to provide continuity, logic and uniformity, where possible. In evaluating the effectiveness of any new installation, one psychological factor that must be taken into account is the "novelty effect," mentioned by Dommasch, et al., (17) and others. In several of the studies reviewed, the researchers clearly did not consider this factor in analyzing their data, thus jeopardizing the validity of their conclusions.

Finally, with regard to the message content of the AAWD, the recommendations of a number of researchers are useful. Hulbert and Burg (13) showed more driver errors in sign comprehension as the number of pieces of sign information increased; thus, AAWD's should be designed to contain only the necessary pieces of information. Hostetter (24) recommends the use of symbols in addition to words, to provide redundancy, and Hopkins (31) recommends the use of a special symbol for unique crossings (such as those used by high-speed trains). Pollock and McDole (7) surveyed driver knowledge of traffic control devices referred to in driver licensing written tests, and found the diamond shape correctly linked to warning images by 96% of their subjects, and the crossbuck shape linked to railroad crossings by all respondents. The circular shape of the standard W10-1 advance warning sign was correctly identified by only 79 percent of the respondents, but addition of the "RXR" to the circular shape raised its proper recognition to 97 percent. With regard to color, yellow and orange were most often correctly linked with their proper connotation. The implications of the Pollock and McDole study are that an "RXR" message on a standard yellow diamond-shape warning sign shows the most promise for conveying the intended message to a motorist.

Markowitz, et al., (32) conducted an extensive study of the design elements contributing to sign effectiveness, and concluded that shape coding was valuable, that red and yellow were readily identifiable colors, that a yellow diamond was a more identifiable color-shape combination than a yellow circle, and that the crossbuck shape is readily identifiable.

3.7 Summary

The review of literature relevant to the present study has revealed pertinent and useful information. However, there is a lack of definitive research directly related to AAWD's. Most of the advance warning devices studied have been modifications of standard devices, and have been evaluated in conjunction with devices at the point of conflict. There have not been any studies in which the critical factors involved in development of an effective AAWD for rail-highway crossings have been examined.

Also, there has not been a high degree of consistency in the results obtained by the different researchers. This makes it difficult to extract "basic principles" applicable to the present study that enjoy unanimity of support from research results available to date. Nevertheless, the literature appears to support several generalizations that have provided guidance in the present study.

First, it is clear to the researchers that using the same advance warning for motorists approaching activated grade crossings as for those approaching passive crossings denies both groups of motorists information that is of value in pre-planning their behavior. Motorists approaching the two types of crossings have different tasks confronting them, and proper advance information will better prepare them to perform these tasks, particularly at a passive crossing where the driving task is more complex.

Next, to be effective the AAWD must be conspicuous. The motorist's first task is to detect the presence of the AAWD, and research has clearly shown that nothing surpasses flashing lights for providing visual impact. Strobes appear more effective than incandescent lights in this regard. Although both red and blue are higher conspicuity colors, they are not consistent with the standard use of yellow as a warning color. Therefore, a standard pair of yellow flashing signals is dictated to preserve continuity with the rest of the highway system.

After the AAWD is detected, its message content becomes critical. It is here that shape and color coding become important, since they are part of the message content. Diamond-shaped signs with black or red characters on a yellow background would be good from a human factors (perceptual) standpoint, and would also preserve continuity. Clarity of message is important. As few elements as possible should be used to convey the desired information. Some combination of symbols and words (or letters) should be used, to provide redundancy. Both the symbols and words should either be already familiar to the motorists or readily interpreted. The use of the familiar "RXR" type message is an example of familiar message content.

Placement of the AAWD is important, as well as its activation sequence. Taking into consideration prevailing speeds, the AAWD should be conspicuously positioned (overhead or on the right shoulder or on both shoulders). It should also be placed at a point in advance of the crossing so when it is activated, drivers have sufficient time to come to a comfortable stop. However, it should not be positioned so far in advance that drivers already past the unactivated AAWD are likely to encounter activated signals at the crossing.

The AAWD should be activated before the crossing signals. This is necessary to build up credibility for the device in the minds of the motorists, as well as to provide a clearance interval for approaching drivers. A consistent, standardized warning time is necessary to aid the motorist in developing reliance on the device and a standardized set of response patterns. Perhaps most critical to the development of credibility, however, is elimination of false activations and unnecessarily long waiting time at the crossings.

The review of the literature also makes clear the importance of proper evaluation of a candidate AAWD, first in the laboratory (indoor or outdoor), and then in the field. There appear to be enough measures of effectiveness currently available to assure that such an evaluation can be carried out effectively. An evaluation of this type should be conducted using a representative sample of drivers, with emphasis placed on obtaining an adequate number of drivers as subjects who have worse than "normal" visual capabilities. The "novelty effect" should also be taken into consideration in evaluating the results.

Finally, the issue of fail-safeness has to be dealt with in any long-range program involving both at-crossing signals and AAWD's. So long as the present requirement regarding fall-back battery power remains, a serious design limitation will continue to be imposed on AAWD's. This issue clearly must be studied in depth, and all of the ramifications of staying with the present system as opposed to converting to a 110-volt system must be explored in detail.

4.0 EXISTING ACTIVATED ADVANCE WARNING DEVICES

This section briefly describes the results of an informal survey of the activated advance warning devices currently in use on U.S. highways to provide additional safety at grade crossings. The survey also revealed a large number of installations in which the advance warning device was active, i.e., always "on"; however, these installations are of less relevance to the present study and, hence, are not included in the discussion that follows.

Of particular interest in the survey were the reasons given to justify installation of the AAWD's. Where available, these "warrants" for specific installations are included with the site descriptions. The complexity of the devices surveyed ranges from a single activated beacon attached to a standard crossbuck or W10-1 sign to a rather elaborate treatment given a freeway grade crossing in California. The decision to use an AAWD generally has been based on local analysis of a problem, and has not necessarily been influenced by any special criteria or warrants, such as may be found in the MUTCD.

4.1 Factors Influencing Use of AAWD

A number of factors have generally been taken into consideration by the responsible authorities in deciding whether or not an AAWD was needed or justified. The principal consideration was the desire to minimize the possibility of accidents resulting from inadequate warning time (distance) provided by the at-crossing signals. Some of the reasons for this inadequate warning time were found to be:

1) High-speed vehicular approaches, as on a freeway, where the driver does not expect to find a rail/highway crossing.

2) High-speed vehicular approaches that have geometric or other features which tend to divert the driver's attention.

3) Crossings where the automatic signals are obscured by the terrain and/or approach roadway geometry.

4) Locations where dense fog, blowing dust, snow, smoke, etc., can be anticipated which may reduce the driver's sight distance or obscure the crossing signals.

5) Vehicle approach gradients which could greatly reduce the driver's sight distance and/or require an increased stopping distance.

6) High-speed train crossings.

Once the determination was made to install an AAWD, it was then necessary to decide on the physical location of the device. Determination of these locations was based on such factors as vehicle approach speeds, sight distances and braking distances for the heaviest vehicles that make use of the crossing roadway. In each instance, the placement of the device, as well as the device itself, was tailored to the specific situation. As indicated earlier, the only common element in all the installations studied was the realization that the motorist needed more advance warning of the train (at or approaching the crossing) than was afforded by the at-crossing signals. Otherwise, the crossings were quite dissimilar, as were the AAWD installations.

4.2 Types of AAWD's in Use

A representative sample of activated warning devices presently in use in advance of grade crossings are described below. They are categorized broadly by type, and an example of each type is depicted.

4.2.1 W10-1 and Signals (Post Mounted)

A number of the installations involve the simple addition of one or more flashing yellow lights to the standard advance warning sign (W10-1) -- either on the same post or an adjacent post. At locations both in Jackson, MO, and in Southern California, one flasher was added to the standard sign. A location near Martell, CA in which two flashers were used is shown in Figure 1. Referring to the photograph, the crossing is straight ahead, but is hidden by the hill on the right side of the road, behind the AAWD. The road is frequently used by heavily laden ore trucks whose drivers experienced difficulty in stopping at the crossing because it is near the base of a long downgrade. Analysis of this situation led highway personnel to add the two flashers to the W10-1. The flashers are activated simultaneously with the at-crossing signals.

4.2.2 W10-1 and Signals (Overhead)

Somewhat more unique than the above are several installations that also involve the W10-1 sign. In Martell, CA, a cantilevered W10-1 flanked by two 12-inch (30cm) yellow flashers is used . In Anne Arundel County, MD (Figure 2), a similar configuration is used with a 48 inch (1.2m) W10-1. The latter installation is augmented by a shoulder-mounted "HIGH SPEED TRAINS" sign and is typical of fourteen such installations used by Penn Central to provide additional safety at crossings used by high-speed Amtrak trains. (These installations are considered interim improvements pending availability of funds for grade separation structures.)

4.2.3 W10-1, Signal(s) With Special Additions

The W10-1 is also a key element in two other AAWD's. In Cochran, CA, an 8-inch (20cm) flasher, bell and floodlight were mounted on the same post as the W10-1. The floodlight illuminates the sign face when it, the bell and flasher are activated by the train detection circuitry (Figure 3). In Florida, there are two sites at which a 36-inch (91cm) W10-1 is supplemented by two 8-inch (20cm) yellow flashers mounted vertically above the sign and a unique 30-inch (76cm) square variable message sign mounted below the sign (Figure 4). When activated, the message plate displays the

Figure 1
Near Martel, CA

Figure 2
Anne Arundel County, MD

Figure 3
Cochran, CA

Figure 4
Florida Device

words "Stop Ahead" in black, 8-inch (20cm) letters on a yellow background. In the non-activated (passive) state, the message displayed is a three-digit number (distance to the crossing) plus the word "Feet".

4.2.4 Railroad Crossbuck

In a rather unique application, the standard crossbuck is used as part of an AAWD in two locations. In Albany, NY, a railroad structure obscures the automatic gates at an at-grade crossing on the far side of the structure. A standard crossbuck was mounted on a pole in advance of the structure, with a flashing yellow light placed above the crossbuck. At a location in the State of Washington depicted in Figure 5, a secondary road intersects with a turning segment of the main roadway. In addition, railroad tracks parallel the main roadway so that the tracks cross the secondary road near the intersection. Drivers turning right from the main roadway immediately encounter the grade crossing. To provide additional warning of the crossing, a device consisting of a flashing yellow light mounted above an illuminated "NO RIGHT TURN" sign and having a standard crossbuck mounted below was installed on the shoulder of the main roadway at a point in advance of the intersection. Both the light and sign are activated simultaneously with the at-crossing signals.

4.2.5 Neon Sign

In an approach developed during the 1930's by the California Division of Highways, a neon "RXR" is cantilevered above the roadway. (Figure 6 depicts such an installation near Stockton, CA.) While earlier installations sometimes used photo cells or time clocks to turn on the signs at night, more recent installations are generally activated by track circuitry. (This was the only AAWD surveyed that did not incorporate flashing yellow lights.)

4.2.6 Prepare To Stop Messages

The message "Prepare To Stop" or a variation thereof has been used in a number of instances to provide advance warning at both crossings and intersections. In one such installation, in Manteca, CA, a cantilevered sign, flanked by 12-inch (30cm) yellow flashers, displays the flashing white-on-black message "Prepare To Stop" when activated by the approaching train. The "Prepare To Stop" message was considered more "fail-safe" than a message such as "Stop Ahead," i.e., it is more credible in the event of power failure. In more recent installations of this type, the lights flash together, alternating with the message.

In several Oregon locations, a constantly-visible message, "Prepare To Stop When Light Flashes" (or, "...When Lights Flash") is used in conjunction with one (or two) train-activated yellow flashers. In Salem, OR, the installation is at an S-shaped freeway off-ramp (Figure 7) with the crossing at the foot of the ramp, as shown in Figure 8. As seen in Figure 7, a W10-1 sign is used as a supplement to provide additional information to the driver.

Figure 5
Washington State Installation

Figure 6
Near Stockton, CA

Figure 7
Salem, Oregon Device

Figure 8
Salem, Oregon Crossing

4.2.7 Special Messages

Another specialized sign was installed in Tracy, CA, at a crossing with railroad gates and was located near a railroad yard. The roadway approach to the crossing was characterized by high vehicle approach speeds. Excessive gate arm breakage led to the development of the device shown in Figure 9, in which fluorescent tubes illuminate the message "RXR GATE" and a yellow light above the sign flashes upon the approach of a train. This AAWD reduced gate arm breakage by 60 percent. It is still in use, although the single flasher has been replaced by two 12-inch (30cm) flashers (with backplates) side-by-side above the message box.

4.2.8 Texas Device

As shown in Figure 10, the device referred to as the Texas sign is a 48-inch (1.2m) circular sign with a yellow background on which is depicted a railroad cross arm and light symbol together with the words "Train When Flashing". Letter height is 6-inches (15cm), which implies roughly a 350 foot (107m) maximum reading distance for people with 20/20 visual acuity. The symbol itself was proposed by Schoppert and Hoyt (2), and would likely have little, if any, driver recognition value without the word "train" on the sign. Yellow flashers are mounted above and below the novel sign. Of all the activated advance warning devices, the Texas sign is the one most thoroughly researched and evaluated over a period of years. Through 1977, there were eighteen sites, each with five or more years of post-installation accident data for comparison with pre-installation data.

4.2.9 Complex Device

One of the most complex AAWD installations was devised for a crossing over U.S. Route 99 near Stockton, CA. Because of the crossing's low volume (less than one train movement per day), grade separation was not justified. The highway had freeway status and, consequently, high approach speeds. Excessive gate arm breakage was anticipated, especially because of the high proportion of truck traffic. Two types of AAWD's were installed for each direction of traffic. Approximately 800 feet (244m) in advance of the crossing, the device shown in Figure 11 was installed on both the right shoulder and the median. This device is similar to that described earlier, in use in Cochran, CA, (see Figure 3) and consists of a W10-1 plus a flasher, bell and floodlight activated by the track circuitry. Another AAWD is located about 500 feet (152m) before the crossing, and consists of an overhead bridge structure supporting a sign that displays the words "STOP TRAIN AHEAD" when activated. This dual device installation has been very effective in minimizing gate arm breakage at this location.

The foregoing indicated that while there is a widespread feeling that such devices are necessary to improve safety in certain problem locations, there is no uniformity of technique, either in selection of the device or in its application. The experiences of those states using these devices provided the project staff with much valuable information which played a major role in the AAWD design and installation recommendations.

Figure 9.
Tracy, CA

Figure 10.
Texas Device

Figure 11.
U.S. Route 99

5.0 SELECTION OF CANDIDATE DEVICES

Development of the candidate devices for evaluation in the present project was an evolutionary process -- beginning with certain design principles, applying practical constraints and taking into consideration the results of prior research and the experiences of states that had developed their own AAWD's for use in problem locations.

5.1 Principles of Design

As part of the design and development of the candidate devices, some desirable properties of the device were defined. They included:

- In both its active and passive states, the device should have a high conspicuity value.
- The device should be fail-safe in the event of commercial power failure. That is to say, the device in its passive state should in no way suggest that there are no trains approaching.
- In its activated state, the following were considered as desirable elements of information for the driver:

    1. There is a crossing ahead,
    2. A train is at, or in close proximity to, the crossing,
    3. You (the driver) must stop ahead, and
    4. Where and when you (the driver) will encounter the crossing.

- In its passive state, the device should transmit the following desirable information to the driver:

    1. That there is a crossing ahead,
    2. Where and when you will encounter the crossing, and
    3. "Be Alert", i.e., watch for the possibility of trains.

It soon became clear that in order to keep costs within reasonable bounds, there were going to have to be some compromises made in terms of which of these desirable elements of driver information were to be stressed. In its passive state, the non-activated portion of the device should have a high target value.

5.2 Practical Constraints

One of the underlying goals of the project was to develop an activated advance warning device which would be an acceptable device to roadway authorities and be designed within the guidelines and constraints of the MUTCD. It was, therefore, necessary to consider some practical constraints.

1) The characteristics and treatment given to advance warning in the MUTCD indicate that advance warning signs are typically diamond in shape and have a yellow background color with black lettering or symbols. Use of the color red (for high target value) in advance warning signs is extremely limited, and normally is reserved for use on signs giving advanced warning of regulatory signs or devices, e.g., "STOP AHEAD" (symbol), "YIELD AHEAD" (symbol) and "SIGNAL AHEAD" (symbol).

2) Although new and different sign shapes and colors might be desirable for "long-run" driver association with grade crossings, what might be gained in a short-term "novelty effect" could be a long-term loss if the driver really doesn't attach any meaning to unique shapes and colors.

3) There are three primary concerns of states and municipalities, namely, installation costs, maintenance costs and the liability aspects of the device itself.

4) It is important that the AAWD satisfy some essential driver needs. Simply stated, in priority order, the driver needs to know:

   a) He is approaching a railroad crossing,

   b) Either there is a train coming or the driving action is specified, e.g., "STOP AHEAD", and

   c) The location of the railroad crossing, particularly when the location is hazardous. For example, the point at which an approaching driver perceives the activated crossing signals may leave him insufficient distance in which to react and bring his vehicle to a stop.

5.3 Suggested AAWD Design Based on Prior Research Results

The literature review revealed information that provided a design framework for the candidate devices. Such design suggestions were, of course, subject to modification due to practical constraints and other considerations. Generally speaking, the following design elements appeared desirable for incorporation in the overall AAWD package:

1) A pair of flashing yellow lights, for conspicuity, redundancy and uniformity.

2) A diamond-shaped yellow sign, for continuity and uniformity -- most warning signs are diamond-shaped although there are rectangular shapes also. Unique shapes such as the W10-1 and W-14-3 are rare. How well the driver recognizes these shapes or what degree of importance he attaches to such recognition has not been clearly resolved.

3) Some version of the present RXR symbol, to take advantage of its ready identification by motorists.

4) A flattened crossbuck (X) in the RXR symbol, to provide a larger target, in the diamond sign, and to provide less symmetry than that provided by a 90° X.

5) Use of the color red within the device to attract the driver's attention and to suggest the serious nature of the traffic control devices ahead.

6) The use of symbols plus words, to provide a level of redundancy.

7) A large device, bigger than minimum standards, to provide adequate legibility for drivers with poorer than "normal" vision.

After consideration of the foregoing factors, together with the general composition of existing, prototype AAWD's, it was determined that a three-component device would best meet the driver's needs for activated advance warning. The three components, shown in Figure 12, are:

1) A pair of flashing lights activated by the train detection circuitry.

2) A primary sign that utilizes a symbol which the driver can readily identify as representing a railroad grade crossing. (Use of a symbolic primary sign is consistent with most international and recent national trends in signing.)

3) A supplemental panel (possibly changeable) mounted below the primary sign and containing a word message to provide additional (and partially redundant) information to the motorist. (If changeable, this message panel would also be activated by train detection circuity.)

5.4 Selection of Light Configuration

Two activated flashing lights are recommended instead of one, because of their proven effectiveness in attracting the motorist's attention and to provide redundancy in case of bulb failure. The lights are mounted vertically, as shown in Figure 12, because this is considered superior to a parallel (horizontal) arm mounting, in that the driving environment already is filled with parallel-mounted, alternately-flashing warning lights that are always on (active). Since the study involves activated lights, it is desirable that the device have minimal driver association with active, alternately flashing beacons.

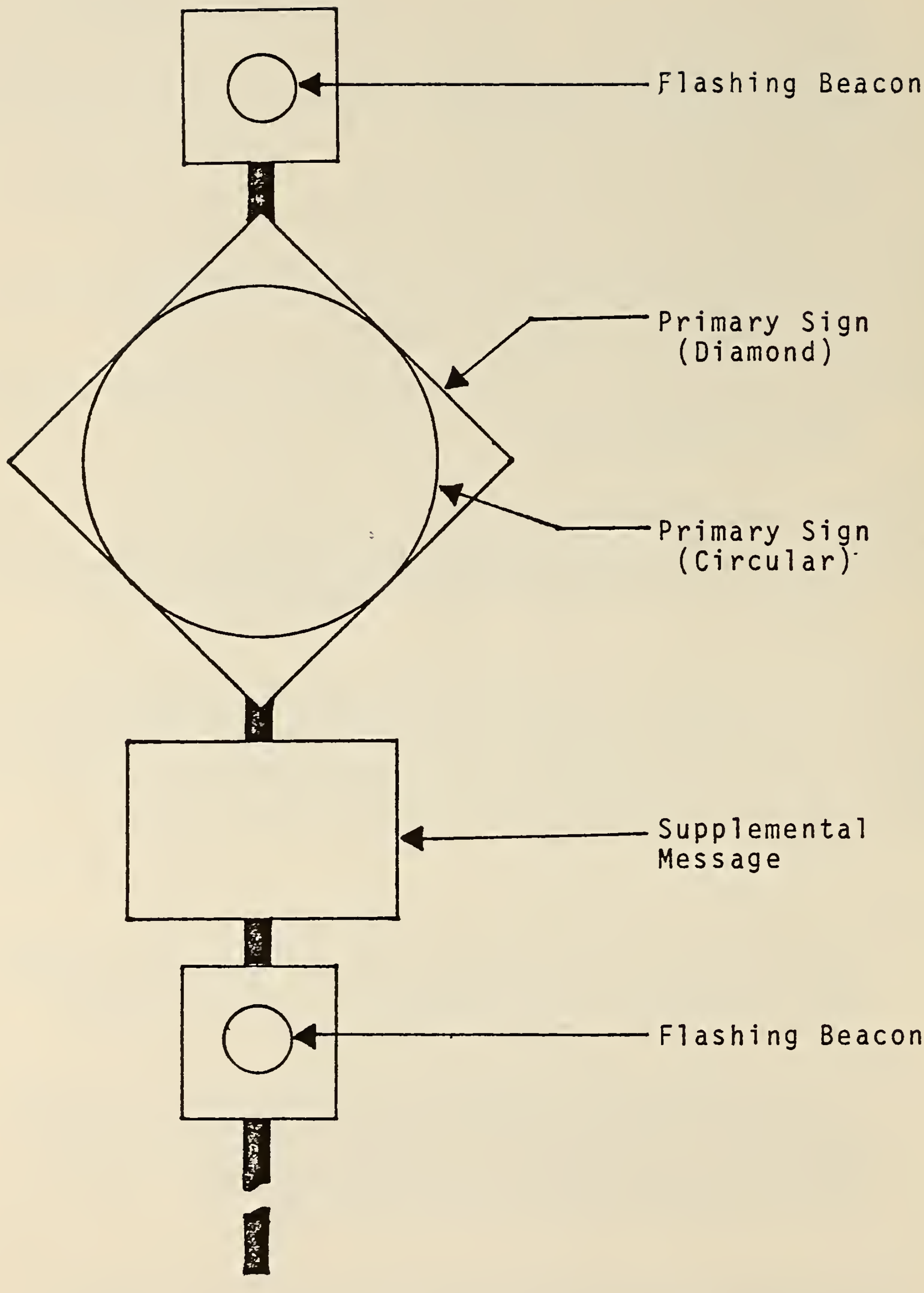


Figure 12
Activated Advance Warning Device

An alternative light mounting that was also considered had two flashing beacons vertically stacked on the top of the support pole, as in the "Florida Sign" described earlier (Figure 4). This alternative has a single advantage over the above - below mounting of Figure 12, in that in the proposed mounting,the lower beacon is more subject to obliteration from the driver's view due to mud splash or physical obstructions such as a large truck. On the other hand, the advantages of the proposed beacon mountings shown in Figure 12 are that the two lights encompass or frame all driver information in the device and, without visual obstruction, will appear as two lights at great distances because of their greater physical separation.

The proposed beacons fit within the context of yellow warning lights, which are commonplace on the highway. Light colors other than yellow might be desirable for long-run driver association with crossings, but it is not clear that unique light colors would improve crossing safety. Greater uniqueness of the light array could be brought about by using three or four yellow signals and various flashing patterns, to develop within the driver a specific association between the light display and railroad crossings that would be effective at great approach distances. However, this would involve a more complex installation with greater capital and maintenance costs and with as yet undemonstrated benefits for actual crossing safety.

5.5 Primary Sign Candidates

Possibly the most obvious choice for a single primary sign would be the existing standard (W10-1). However, several novel signs were designed for laboratory testing, along with the W10-1, for the following reasons:

- The Railroad Grade Crossing Passive Signing Study (4), culminated in recommendation for long-term replacement of the existing W10-1 in advance of crossings without active devices.
- The results found by Pollock and McDole (7), indicate the circular uniqueness of the black on yellow W10-1 may not be driver-appreciated. This conclusion, in conjunction with other research, raises questions as to whether the standard advance warning sign is being seen and "registered" in the driver's mind.
- Past experience of the researchers in dealing with uninformed test subjects has revealed their inability to say for certain the sign color or shape upon which the RXR symbol appears.
- Since the unique circular shape of the W10-1 is apparently not recognized by drivers, the RXR symbol found on the W10-1 would gain more attention from placement on the standard diamond shape. One thus achieves additional conspicuity from increased sign size (21.5%) for the same material cost.

Because of time and budget constraints and the complexity of the experimental design, it was determined that only four primary sign candidates would be evaluated. Because it is the national standard, the W10-1 was included as a candidate, permitting a choice of three experimental signs to also be evaluated.

From survey of a number of states and governmental agencies it became clear that the common thread between existing AAWD installations was the concern or feeling that activated crossing signals were not providing the approach vehicle driver with sufficient time to perceive, react and stop his vehicle. The survey further revealed that any acceptable warrant(s) for AAWD installation must be constructed around the likelihood that the crossing signals were not providing "safe stopping sight distance" (See section 9.0).

A further review of existing installations revealed that the majority of existing sites required AAWD advance roadway placement where the crossing is hidden or out of direct down-the-roadway driver view as he approaches the crossing. Because of this, an extensive effort was devoted to evaluating the potential driver understanding of both a directional arrow and a railroad crossing warning message within a single warning sign. The researchers considered the possibility of a separate directional arrow plate in addition to the primary crossing warning sign. However, this possibility was ruled out due to the undesirable "totem pole" like array of flashing lights, primary sign, directional arrow plate and a supplemental message plate.

It was reasoned by the researchers that, if understood, the railroad crossing symbol and directional arrow would be a highly credible sign and as such would continue to attract the driver's attention. It was reasoned that communication of the message "railroad crossing in or around a curve (turn) ahead" is more desirable than the limited message "railroad crossing" which relies on the driver to deduce its location, provided he has time to exercise such logic and deems it necessary to do so. The researchers believe that the provision of the railroad crossing and the locational information supplied by the directional arrow is in keeping with the concept of "Positive Guidance"(33).

5.5.1 Primary Sign A

The primary sign candidate designated herein as Sign A and shown in Figure 13, is the standard passive advance warning sign, W10-1, specified by the MUTCD. The sign was chosen as one of four principal candidates because it is the national standard, and because it can be simply "added-to" to create an activated device. The sign, with its circular shape and RXR symbol filling the entire sign surface area, does not lend itself to the use of an arrow within the sign, since any arrow located in the upper of lower quadrants would have minimal size and hence minimum resolution distance. Sign A, therefore, was the only candidate which did not have an arrow option.

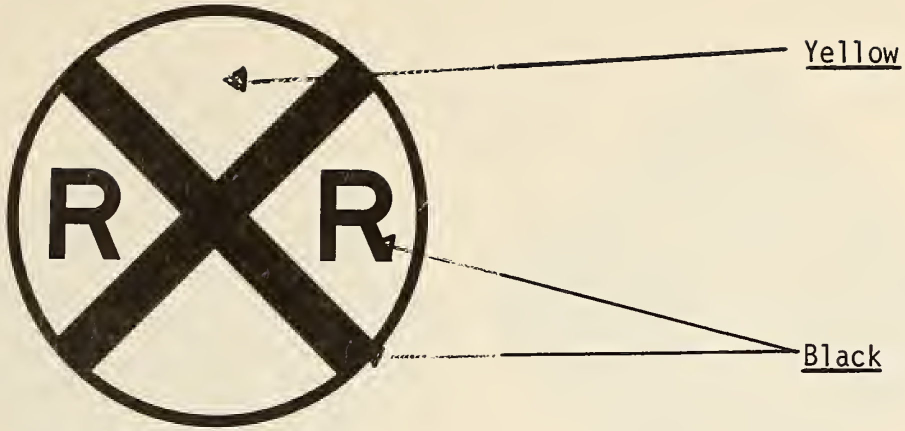


Figure 13
Primary Sign A (W10-1)

5.5.2 Primary Sign B

Primary sign candidate B is shown in Figure 14 with three of the six arrow options studied. The arrow options are designated: none, vertical, curve (right and left) and turn (right and left).

This sign was designed to have the following desirable properties:

1) It has a diamond shape with a black legend on a yellow background, which conforms to the national standard for signs warning of roadway-located hazards ahead.

2) It incorporates a red X for increased target value.

3) It uses an X bracketed by two R's (RXR), which has been shown to be meaningful to drivers as a symbol warning of a railroad crossing, Pollock and McDole (7).

4) The flattened (60^0), red X provides the desirable assymmetric symbol properties described by Jacobs, et al. (8). This flattened X also has the advantage of being 5-10% longer in length than the 90^0 X of the W10-1.

5.5.3 Primary Sign C

Figure 15 shows Sign C, with three of the six arrow options. As can be seen, the sign incorporates the circular, W10-1(*) symbol, with red upper and lower quadrants along with an appropriate arrow within a yellow diamond sign. As depicted in Figure 15, the red modified W10-1 symbol has a diameter one-half the dimensions of the diamond sign. It is possible, however, to increase the size of the (*)symbol to 5/8 the dimension of the diamond sign while still retaining sufficient sign area to display the arrow.

(*) 

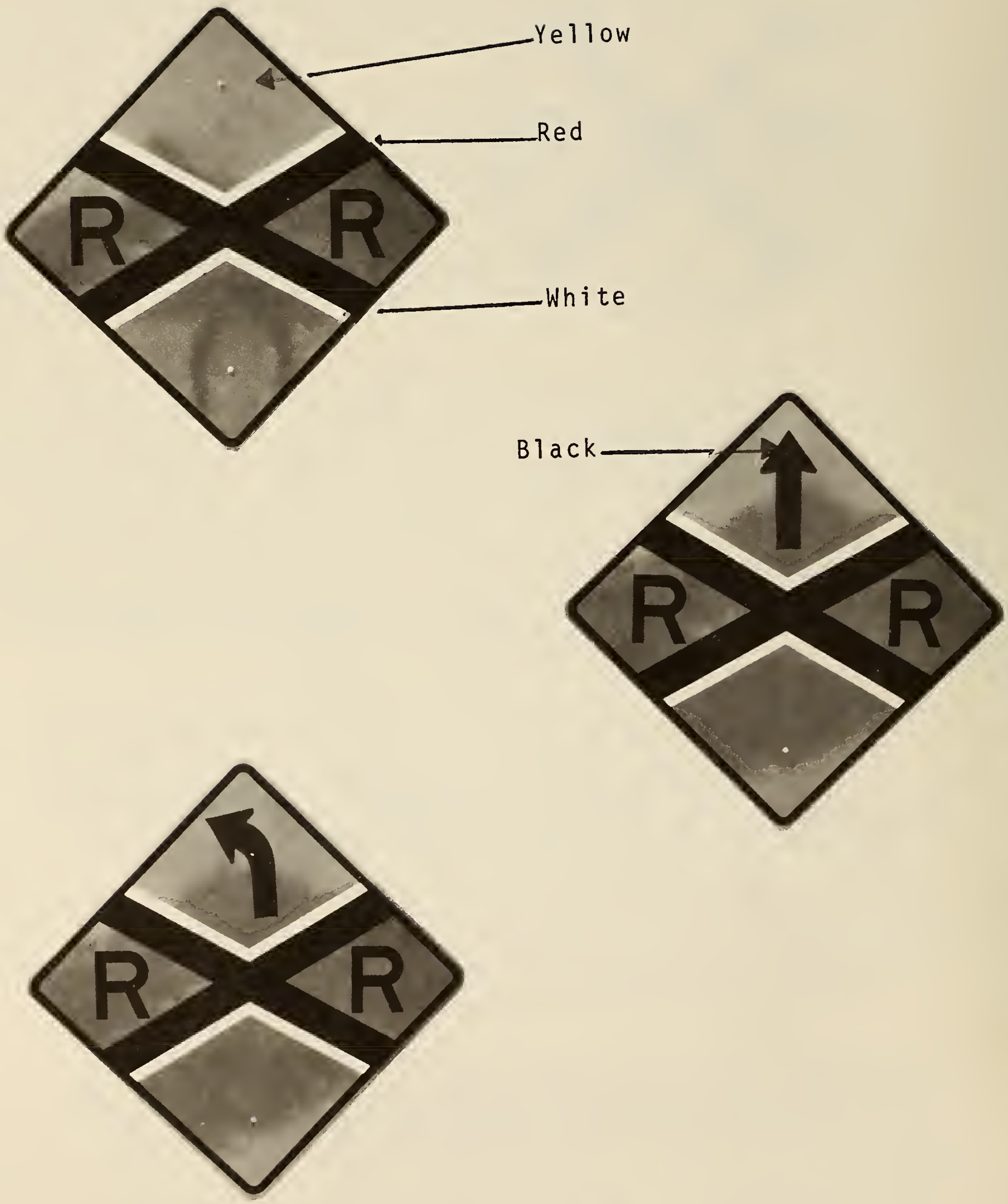


Figure 14

Primary Sign B
(With Three Arrow Options)

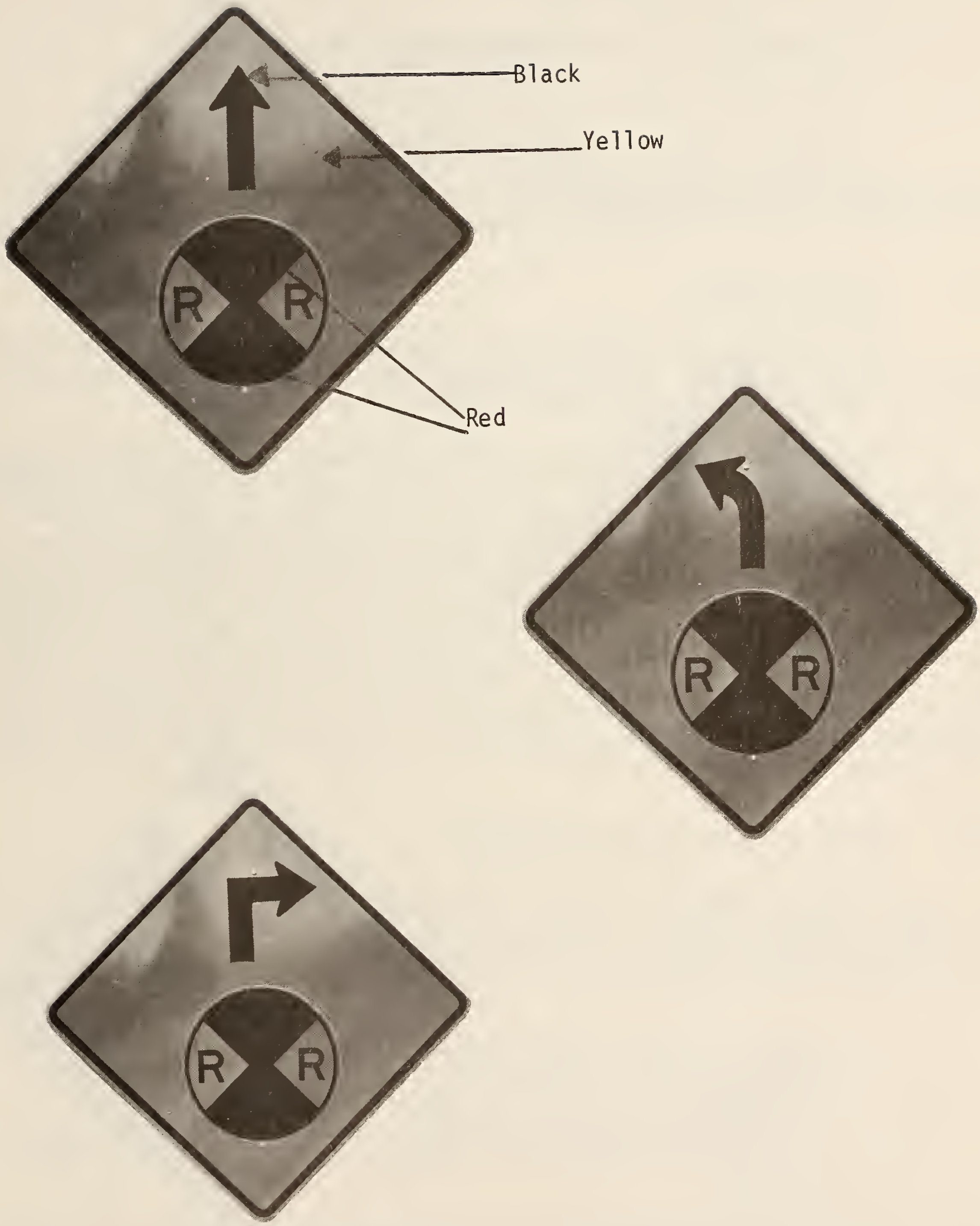


Figure 15

Primary Sign C
(With Three Arrow Options)

The positive qualities of the primary Sign C include:

- A yellow diamond shape,
- A circular railroad warning symbol and
- Use of the color red to provide increased target value.

A negative aspect of Sign C is that compared to Signs A, B, and D, it would have to be approximately 60% larger in order to communicate the same railroad crossing message over any fixed viewing distance.

5.5.4 Primary Sign D

Sign D is shown in Figure 16, once again with three of six arrow options. It is identical to Sign B except that it has no black border and it has upper and lower black quadrants, with white arrows.

This sign was designed to provide the best contrast against both light and dark sign backgrounds. Unlike the conventional yellow background warning sign with narrow black border only the side quadrants will stand invisible when silhouetted against a brown, dry, grass-covered hillside. The narrow white border on Primary Sign D provides contrast between the red and black areas of the sign. There is roughly a 10% increase in the dimensions of the red X of Sign D over the red X of Sign B, due to the lack of a border on Sign D. Observed against a dark background, the black area of the sign tends to disappear, giving a unique "bow-tie"-like shape to the sign, with a white arrow (when used) suspended over the bow tie. Observed against bright backgrounds, the yellow of the sign tends to disappear, exhibiting a complementary shape to that of the bow tie.

5.5.5 Other Primary Signs Considered

In the process of selecting the three new, i.e., experimental, primary signs described above, a number of other signs were considered. Four such signs, designated Signs E, F, G, and H, are shown in Figure 17. The signs and the basic reasons for their rejection are discussed below:

1) Sign E. Based on the results of a recent FHWA/FRA-sponsored study (4), this sign, a modified version of the W10-1, was recommended to the NAC to replace the W10-1 in advance of crossings with passive devices. The request was denied. The sign was rejected for project consideration for several reasons:

    a) The sign design was such that incorporation of arrows was not practical.

    b) Due to the rarity in which drivers encounter trains at railroad crossings, the unique circular shape and its driver association with railroad crossings may be more fantasy than fact. Thus, a larger diamond, or rectangle shape, for the same material costs would therefore seem preferable.

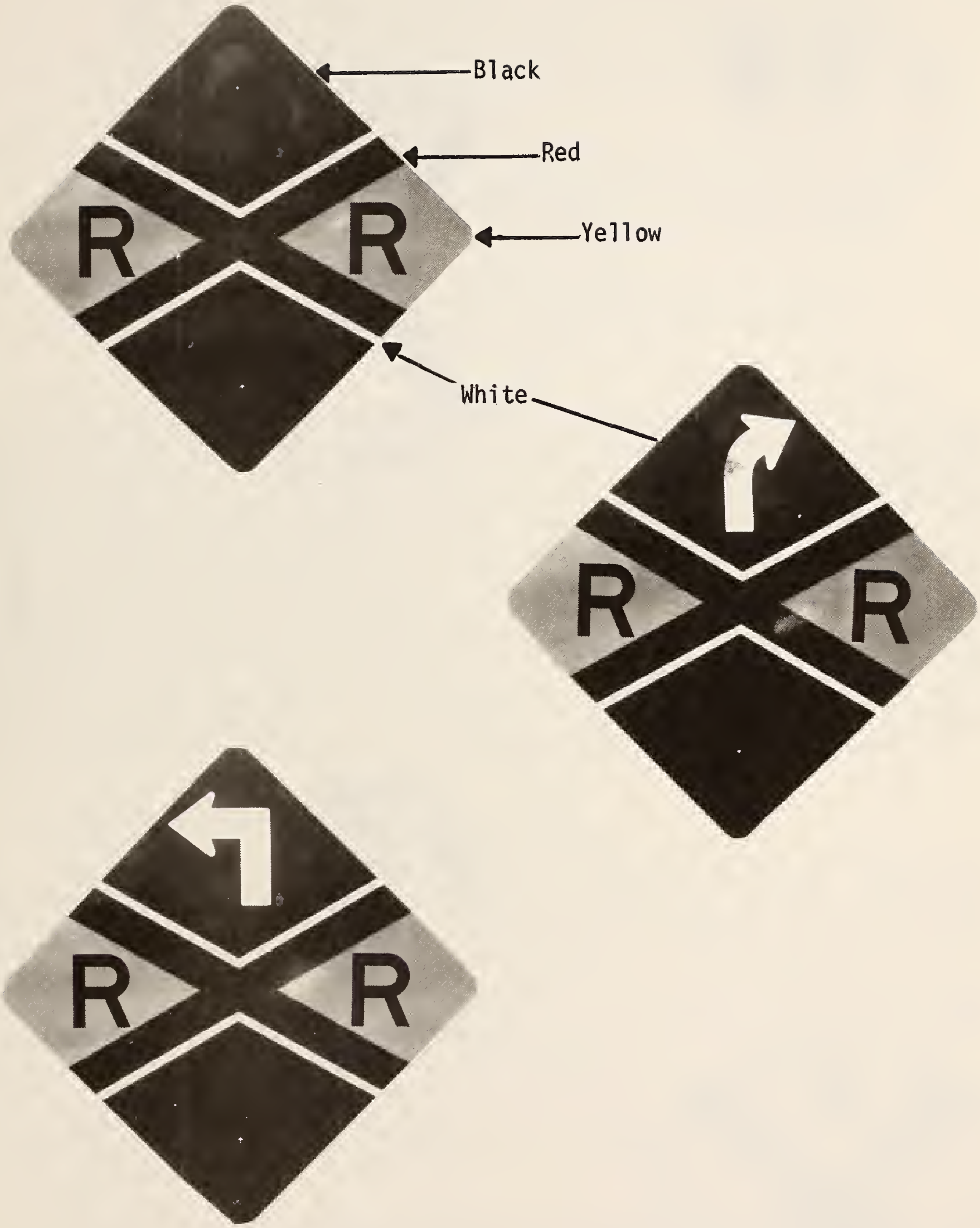


Figure 16

Primary Sign D
(With Three Arrow Options)

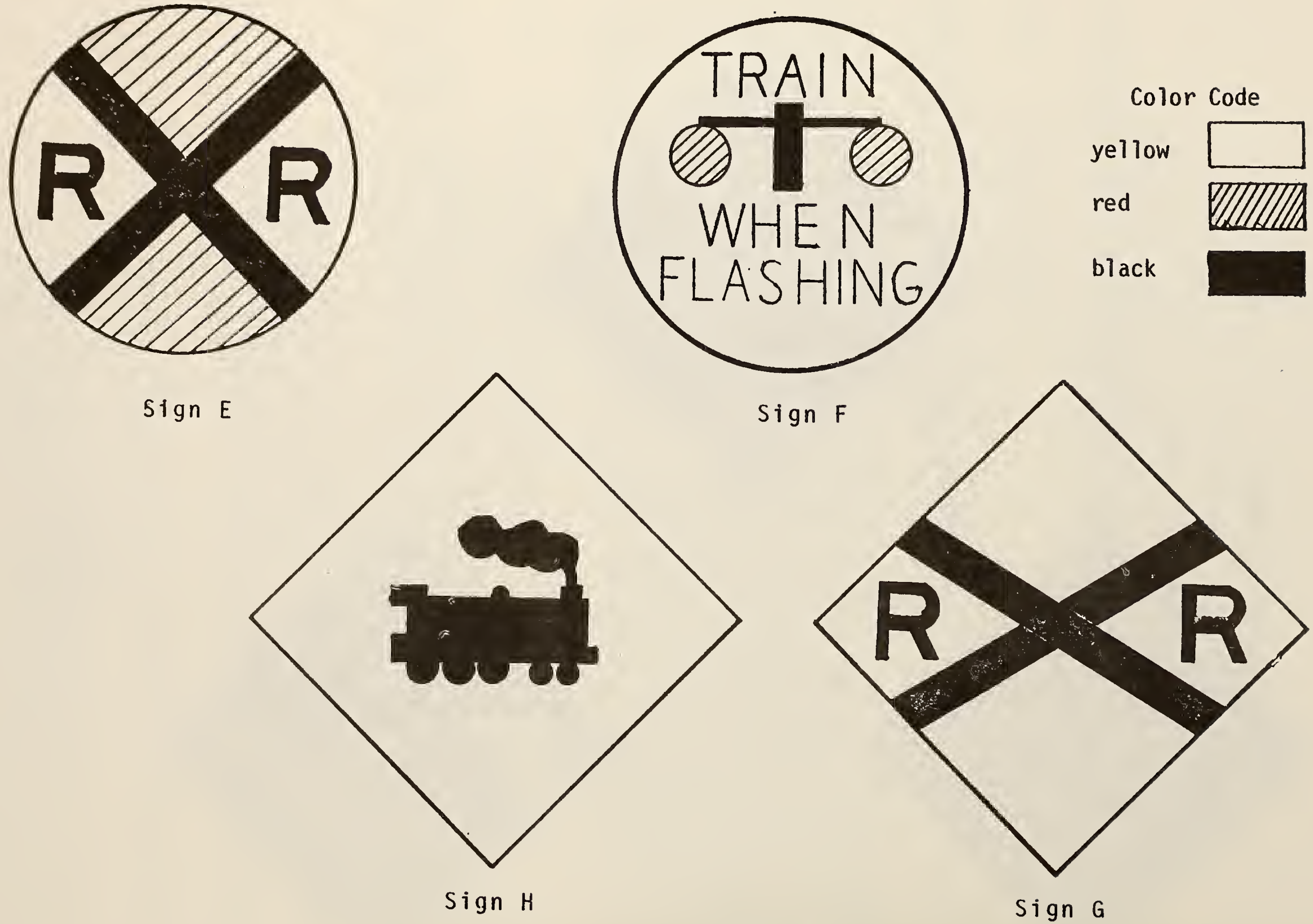


Figure 17
Other Primary Signs Considered

2) Sign F. Sign F is the "Texas" sign, shown in Figure 10. This sign wasrejected because it is not fail-safe, due to the constantly-visible word message. Without the word "TRAIN", the symbol is not likely to be understood. Again, the sign was felt to be less desirable because of its circular shape.

3) Sign G. A locomotive symbol has unproven ability to elicit driver understanding of its intended "railroad crossing" meaning. The steam locomotive symbol is poor in terms of the distance at which it can be identified versus its size.

4) Sign H. A strictly black on yellow version of Sign B, black X and no white border, was rejected because Sign B has more target value.

In addition to the above signs, considerable attention was given to the use of a black-on-yellow diagrammatic sign that depicted a railroad track crossing a roadway. It soon became apparent that use of such a diagrammatic sign might require a whole series of signs, each totally different and, in addition, informal testing of some candidate diagrammatic signs revealed that they may not readily be understood by many drivers (a finding in keeping with some previous studies of diagrammatic guide signing). As a consequence, diagrammatic signs were dropped from primary sign consideration and subsequent detailed study. This decision was dictated primarily by funding limitations of the project and the amount of work projected in order to optimize the distinctiveness and resolution characteristics of a track/road symbol. Such a symbolic sign would have application for the special situation occurring at a railroad crossing and a closely spaced intersection.

5.6 Candidate Supplemental Message Warnings

Considerable time and effort went into the evaluation of supplemental message panels for the AAWD. The project staff considered it most desirable for this panel to have a two-message capability, one message for the activated state and one for the non-activated (passive) state. If the panel were designed to "blank out" when not activated, it would be more resistant to long-term "tune-out" by motorists, but would give no supplemental crossing warning in its passive state. Furthermore, blank-out operation could be misinterpreted in the event of power loss when a train was indeed at, or approaching the crossing. There are additional reasons for a passive message warning of a crossing ahead in the absence of a train. For example, awareness of the crossing would minimize the unexpected appearance of a stopped vehicle at the crossing, e.g., a school bus.

Having concluded that a changeable message sign was desirable, the researchers gave consideration to various techniques for providing this capability. A review of the installation and maintenance costs of matrix message signs ruled out their use as impractical. An evaluation of internally-illuminated signs such as are currently in use in a number of applications, described in Section 3.0, led the researchers to rule out such signs for the following reasons:

1) Excessive initial and maintenance costs.

2) Excessive size (and cost) required to provide adequate message size.

3) Off-the-shelf hardware was not appropriate, necessitating special development costs that would not be cost-effective for such a limited market device.

4) There are less costly ways (mechanical) to provide a changeable message capability.

In terms of the laboratory testing, consideration was given to two fundamental devices: a single non-activated or non-changeable message plate located beneath the primary advance warning sign and a similarly-located changeable message unit displaying one message in its activated state and another message in its passive or inactive state.

Eight messages and a blank message were developed and considered candidates for display on the supplemental plate. They are shown in Table 1. A 2x3 foot (0.6 x 0.9m) plate was determined to be proportionately correct to accompany the 48-inch (1.2m) diamond sign, and also permitted the use of at least 5-inch (13 cm) letters to form the candidate message. The STOP AHEAD, STOP AHEAD FOR TRAIN, TRAIN WHEN FLASHING and TRAIN COMING messages are to be considered employable only with an activated (changeable) message plate.

There are differing "schools-of-thought" regarding what a supplemental message should tell the driver. The STOP AHEAD message reflects the viewpoint of those who emphasize telling the driver what to do ahead, as opposed to those who prefer informing the driver what lies ahead, e.g., TRAIN COMING. The message STOP AHEAD FOR TRAIN was the researchers' best effort at satisfying both of these opposing views. The fourth, activated only, message was TRAIN WHEN FLASHING, which is driver informational (TRAIN) and explains the meaning of the flashing signals. The PREPARE TO STOP message is considered a liability-covering, second choice for those who would propose STOP AHEAD. Likewise, the WATCH FOR TRAINS message would be an analogous second choice for an activated message for those who would propose TRAIN COMING but might worry about false activation of the message and hence the liability consequences. Both the PREPARE TO STOP and the WATCH FOR TRAINS messages are considered driver alerting messages for inactive (no train coming) display. As an activated message, PREPARE TO STOP, transmits far less decisive driver information than either the STOP AHEAD or TRAIN COMING messages. The same can also be said for the WATCH FOR TRAINS message when used as an activated message. The RAILROAD XING AHEAD message contains somewhat more information, AHEAD, than each of the primary signs, without arrows, i.e., the driver must deduce AHEAD from the primary sign location. On the other hand, the RAILROAD CROSSING AHEAD message contains less driver information than what is intended from a primary sign and arrow, i.e., more specific locational information. Were it not for the foregoing, one might consider the RAILROAD XING AHEAD message to be an excellent choice for the contents of an educational tab to be temporarily mounted beneath a new symbolic sign. The message, 750 FEET, was intended to satisfy those who desire additional information, in this case, the distance to the crossing. Considered only as a passive message, this type information is displayed by the Florida Device (See Section 3.). The blank message, #9 in Table 1, was chosen to encourage subject participation in the questioning by allowing them the option of formulating their own message (limited to four words or less).

TABLE 1

CANDIDATE SUPPLEMENTAL MESSAGES

STOP AHEAD #1	TRAIN COMING #2	STOP AHEAD FOR TRAIN #3
TRAIN WHEN FLASHING #4	PREPARE TO STOP #5	RAILROAD XING AHEAD #6
WATCH FOR TRAINS #7	750 FEET #8	#9

Further reasons for message choices and the results of some informal subject tests are listed below:

1) "PREPARE TO STOP" was included primarily because of the extensive current application of this message (in California) in advance of traffic signals located on high-speed rural roads. This flashing sign has been used both actively (always on) and in an activated mode.

2) The "WATCH FOR TRAINS" message was a modification of a "LOOK FOR TRAINS" message suggested by Schoppert and Hoyt (2). Use of the word WATCH (rather than LOOK) was documented in research by Hanscom (21) in evaluating active and passive signing to alert drivers to a potential icy bridge. Although not tested, it was the researchers' contention that "watching for trains" was the desired driver reaction and could best be achieved by the direct suggestion to do so, rather than an indirect command or suggestion, LOOK.

3) The "STOP AHEAD" message is currently used (activated state) by the Florida device. (See Figure 4).

6.0 INDOOR LABORATORY TESTS

The candidate activated advance warning devices described in the previous section were subjected to a laboratory evaluation procedure designed to select those showing the most promise for subsequent field testing. The laboratory evaluation consisted of an indoor test procedure, utilizing group viewing of motion pictures and slides, followed by "outdoor laboratory" testing on a closed course in which individual subjects made observations, while driving, of full-scale AAWD's realistically positioned alongside the road. This section describes the indoor testing activity, while the outdoor testing is described in the following section.

6.1 Motion Picture Tests

6.1.1 Procedure

The indoor laboratory testing consisted of two parts -- motion picture testing and slide presentation testing. The efficacy of both of these techniques had been established in earlier research conducted by Burg and Hulbert (9); Forbes, Fry, et al. (10); Forbes, Pain, et al. (15); and Hulbert and Burg (13). The purpose of the motion picture testing was to determine subject responses (in terms of recognition and assumed meaning) to the four candidate primary signs, shown in an appropriate highway context either with or without an arrow, and without supplemental message panels. Motion pictures of these signs as they would be viewed by an approaching driver were filmed and then spliced into an already-available 16mm film, produced by the American Automobile Association (AAA). This film contained motion picture scenes of other traffic control devices (signs, signals or pavement markings) similarly viewed. The AAA film had been developed for driver testing of new (or novel) traffic control devices. The film, which is narrated, shows more than 20 sequentially-numbered scenes, and is designed for presentation to large audiences. Selected scenes from this film, minus narration, were combined with project-produced film scenes to compose the films shown to the study subjects.

Only nine of the possible combinations of the four primary signs and six arrow options could be filmed and evaluated, due to time and budget constraints. These combinations are shown in Table 2. Full-scale 48-inch (1.2m) signs were mounted on posts in standard locations alongside the roadway. These signs were then 16mm photographed from the driver's eye level in an approaching vehicle. Figure 18 shows the roadway context in which eight of the nine sign/arrow combinations were filmed. The figure shows Sign Combination No. 6 mounted at the side of the road. This roadway scene, viewed at longer range, shows the roadway curving to the left as it proceeds over the crest of a hill. The ninth sign/arrow combination, a right turn arrow with Primary Sign B (Combination No. 4) was filmed in the context of an approach roadway and a parallel railroad track, Figure 19. The crossing lies out of the scene, beyond a right turn at the intersection.

		ARROWS			
		NONE	↑	↰	↱
SIGNS	PRIMARY SIGN A	1			
	PRIMARY SIGN B		2	3	4
	PRIMARY SIGN C	5		6	
	PRIMARY SIGN D	7	8	9	

Table 2

Primary Sign and Arrow Combinations Tested

Figure 18
Scene Filming Location 1

Figure 19
Scene Filming Location 2

A total of 333 subjects participated in the motion picture tests -- 36 licensed drivers (ages 17-60 and who were paid for their time) and 297 high school driver education students. The subjects were tested in groups (drivers separately from students) ranging in size from 5 to 60. The drivers were the first subjects tested, generally in small groups, and their responses constituted the first data base. The student subjects were added subsequently, when it was decided to expand the data base and this group of subjects became available for (large) group testing. Somewhat different testing procedures had to be devised for the two types of subjects.

Of the nine film scenes created for the project, driver subjects saw six (Combinations 1,2,3,5,7 and 9 from Table 2). A film was assembled for each group of subjects and consisted of two of these six test scenes plus nine scenes chosen from the AAA film. In each assembled film, the test scenes were the fourth and ninth scenes in the sequence of eleven scenes. This provided adequate temporal separation between the two and avoided any learning effects that might have taken place early in the sequence.

Collectively, student subjects saw only four of the test scenes (Combinations 1, 4, 6, and 8). As seen from Table 2, these four combinations included all four primary signs and the four basic arrow conditions (none, vertical, curve and turn).

In each test session, the subjects were told to assume they were driving down a road, and that in each projected scene they would come upon a sign, signal light or pavement marking. The film was stopped after each scene to provide time for the subjects to write their explanation of what the device meant to them. In addition, the subjects were asked to code their level of confidence in the correctness of their response.

Because they were tested in smaller groups and more time was available for their test sessions, the licensed driver subjects were further asked to identify the following:

1) how effectively they felt the device conveyed the message they felt should have been conveyed in the highway setting given,

2) what their criticisms were, if any, of the device displayed, and

3) any suggestions they had for improving the device display and/or informational content.

The driver subject response form (one for each scene) is shown in Figure 20.

The student subjects were given a simpler response form, the first page of which is shown in Figure 21. For each scene, the traffic control device was pointed out to them and they were asked to describe its meaning clearly and in as few words as possible. They were told they would see signs, signals and pavement markings, some of which may be unfamiliar. It was further explained that their responses were to be scored correct or incorrect based on the <u>intended</u> meaning of the device. The students also were asked to

MOTION PICTURE PRESENTATION

Test Driver #__________ Date________________

Driver Scene #__________

Write down your best estimate of what the traffic sign(s), signal(s), light(s) or pavement marking(s) told you about the situation you were approaching in the film (the moderator will point out the special scene (device) to which you are to respond)

____

____

What is your degree of confidence in the correctness of the above answer?

very confident		fairly confident		not confident at all
☐	☐	☐	☐	☐

How well did these sign(s), signal(s), light(s) or pavement marking(s) tell you everything you feel you should have known about the situation you were approaching?

very well		fairly well		not well at all
☐	☐	☐	☐	☐

a) What was wrong (if anything) with what was there? ________________

____

____

b) What should have been there? ____________________________________

____

Figure 20

Driver Subject Response Form

Write down your best estimate of what the traffic sign(s), signal(s), light(s) or pavement marking(s) told you about the situation you were approaching in the film (the moderator will point out the special scene to which you are to respond)

Scene #1 ______________________________

____

______________________________ [ ]

Scene #2 ______________________________

____

______________________________ [ ]

Scene #3 ______________________________

____

______________________________ [ ]

Scene #4 ______________________________

____

______________________________ [ ]

Scene #5 ______________________________

____

______________________________ [ ]

Scene #6 ______________________________

____

______________________________ [ ]

Figure 21

Student Subject Response Form

weigh their own confidence in their response to each scene on a scale of 1 (very sure) to 5 (very unsure), and to place this number in the rectangular box appearing with the scene numbers on the response form. (Due to large class sizes, the students were also cautioned to answer individually and not to compare notes with their neighbors.)

The first film scene shown to every subject group was used solely for providing the group with practice in the test procedure. Response sheets were collected, quickly reviewed and any apparent misinterpretation of the procedure corrected. Also, questions were answered at this time. Subject responses to this first scene were not included in any of the data anaylses.

6.1.2 Results of the Motion Picture Tests

Since only one scene, that containing the standard sign, was viewed by both groups and because of differences in the nature and complexity of the responses sought from the student and driver groups, data from the two subject groups were analyzed separately at first, and subsequently combined, where feasible.

Driver Responses

Analysis of the drivers' responses to the AAWD's sought to answer the following questions:

1) How complete was the message received by the subject? For example, did he understand the basic fact being told him, i.e., that there was a railroad crossing ahead, in his path? If so, did he understand the crossing to be straight ahead, or around a left turn or a right turn?

2) How adequate did the subject think the AAWD was in conveying the message that should have been conveyed?

In answering the first question, one of two possible scores (0: did not recognize; or 1: did recognize) was used to characterize the subject's response with regard to each of three levels of expressed understanding. These are:

LEVEL 1: Fundamental meaning, i.e., railroad crossing

<u>Level 1</u> indicates that the subject has merely read the sign, and associated it with a railroad crossing, but has not gone beyond this -- by placing the crossing in the context of the roadway and his own path.

LEVEL 2: General locational meaning, i.e., railroad crossing ahead

<u>Level 2</u> reflects a higher-order cognitive awareness of the sign's meaning in which the subject properly understands that the crossing lies ahead <u>in his path</u> (as referred to by the sign) and is of relevance to him. (Typical Level 2 responses included phrases such as "ahead", "down the road", "coming up", etc.)

LEVEL 3: Specific locational meaning, i.e., railroad crossing around a turn or curve, over the hill, etc.

Level 3 response shows that the subject has extracted the maximum possible information from the sign message as seen in the context of the roadway.

Table 3 categorizes driver subject responses to the six test scenes. Since each of the 36 driver subjects saw only two test scenes, a total of 72 responses were obtained. It should be mentioned that all film scenes terminated as the camera car was about to pass the AAWD, with the sign image located in the upper right hand portion of the projected roadway scene. Unfortunately, when compared with the nine AAA scenes, which generally either employed stop action (freeze framing) or zoomed in on the device depicted in a scene, the project-generated test scenes were inferior, in that they gave the subject far less time to view the depicted AAWD clearly. As a consequence, a number of the 36 driver subjects complained of inadequate viewing time or of an unclear image of an AAWD. Despite this difficulty, the degree to which subjects correctly interpeted Signs B, C and D, all of which were new to them, was quite high.

As indicated in Table 3, two subjects scored general locational (level 2) response to the left curve arrow within Signs B and D. In each case, the subject failed to integrate the railroad crossing message with the curve message, interpreting the sign to mean "railroad crossing ahead, and the road turns". However, 15 of 20 subjects (75%) correctly gained specific locational (Level 3) understanding from these two sign/arrow combinations, a very respectable showing considering the novelty of both the signs and the arrow-within-a-sign concept. No specific locational responses (level 3) were expressed by subjects viewing Signs A or C and D, without arrows. One might expect at least one subject to perceive the road curving over the hill and say the crossing was over the hill or around the curve. The fact that no such responses occurred indicates that these sophisticated deductions may be beyond what can be expected from the average driver.

In reviewing subject responses to Sign A and Signs C and D, without arrows, 9 of 16 (Sign A) noted the crossing lay ahead which says 56% of the respondents viewed the crossing within the roadway context (or knew it was an advance sign) and responded with the general location, i.e., the crossing lay ahead. The remaining 7 subjects apparently read the sign only, i.e., railroad crossing. Sign D scored 7 of 16 general locational responses along with complaints that the sign was difficult to see in the film, i.e., too much black. On the other hand Sign C scored 7 of 9 general locational responses. Due to small sample size, however, no statistical significance can be attached to differences between response levels 1 and 2 to Signs A, C and D.

The vertical arrow with Sign B elicited no specific locational response although 8 of 10 subjects gave general locational responses. However, as shown in Table 3, 4 of the 8 subjects said the crossing lay ahead and the road goes straight. This points out that there is definitely a subgroup of drivers which will read a vertical arrow, of the type tested, as

TABLE 3

DRIVER SUBJECT RESPONSES (MOTION PICTURE TESTS)

TEST SCENE (Sign/Arrow Combination)	Correct Responses			Incorrect Responses	Total Sample
	Railroad Crossing	Railroad Crossing Ahead	Railroad Crossing Location		
Sign A, without arrow	7	9	-	-	16
Sign C, without arrow	1	7	-	1	9
Sign D, without arrow	7	7	-	2	16
Sign B, with vertical arrow	1	8*	-	1	10
Sign B, with left curve arrow	-	1*	7	2	10
Sign D, with left curve arrow	1	1*	8	-	10

SIGN A: Black on yellow, circular standard sign, MUTCD designation W10-1;
SIGN B: Black on yellow diamond with red 60^{o} X and white border;
SIGN C: Black on yellow diamond, with circular, red modified RXR symbol;
SIGN D: Borderless diamond sign with RXR symbol, red 60^{o} X with white border, yellow side quadrants and black in upper and lower quadrants.

Black arrows with signs B and C, and white arrows with sign D.

* Includes responses of the type 1) railroad crossing ahead, or 2) railroad crossing ahead and the road goes straight (vertical arrow).

being "road-information" rather than reading it as AHEAD, with first exposure. Whether these results are good or bad, depends upon the intention of the vertical arrow usage. The intention of its usage herein was to provide specific locational information (over the hill) and the desired results were not achieved. Considering the other 4 (of the 8) subjects who merely stated railroad crossing ahead versus the one subject who merely read railroad crossing and comparing these results with Sign C without arrow, points to the possibility that a diamond sign shape without any arrow could be as effective as one with a vertical arrow in transmitting the concept of AHEAD.

Since it was the goal of the researchers to evaluate the possibility of driver understanding of specific locational information supplied by sign arrows, the following conclusions were reached at this point of the experimentation:

1) Larger data samples were needed.

2) The vertical arrow showed little promise for communicating that the crossing lay over or beyond the hill (vertical sight distance obstruction).

3) The curve arrow showed excellent potential for transmitting specific locational information, i.e., the crossing lay in or around the curve ahead.

4) A large number of subject responses were needed for the turn arrow, yet to be shown.

The results demonstrated by the driver subjects regarding their understanding of the primary signs coupled with their comments on the response form, Figure 20, were as follows:

1) Sign A: All 16 subjects identified the railroad crossing meaning. There were several complaints (4) that more information was needed.

2) Sign B: Two of 23 subjects failed to properly identify the crossing meaning; however a third subject called it a railroad stop ahead and was, therefore, classified as being incorrect. Complaints were that the R's were too close to the red X and hard to read -- the R's were in fact poorly centered in the side quadrants of the prototype sign, Figure 14, a situation that is magnified by poor resolution characteristics of 16mm film as compared to the human eye.

3) Sign C: Eight of nine subjects correctly identified the crossing warning message. The film-projected image of the red modified W10-1 symbol was half the size of other primary sign RXR symbols and presented resolution difficulties with some subjects.

4) Sign D: The railroad crossing message was correctly identified by 24 of 26 subjects. Frequent subject comments were that the sign had too much black, making it hard to read and the R's were once again located too close to the red X.

Student Responses

To obtain much larger data samples while minimizing the cost of obtaining the data, the researchers were able to obtain subject responses from 297 high school driver education students. This group ranged in age from nearly 16 (within a few months) to 18 years and were primarily high school sophomores and juniors.

Four primary sign and arrow combination scenes were selected for student responses. The rationale for this selection was to show one scene of each of the primary signs, as well as to present four arrow possibilities, i.e., none, vertical, curve and turn.

The results of analysis of student, written responses are shown in Table 4. The category labeled "incorrect" includes:

1) Wrong answers, with some indication the student was "trying",

2) Some apparent guesses, intended to be humorous, and

3) Statements that the respondent did not understand.

As seen in Table 4 the frequencies shown in the correct category RAILROAD CROSSING AHEAD, general locational response, included responses of the type:

1) Railroad Crossing Ahead, or

2) Railroad Crossing Ahead and the road goes straight (vertical arrow), curves (curve arrow) or turns (turn arrow).

Separation of the arrow meaning from the railroad crossing message was as follows:

1) Sign D with vertical arrow: Two subjects responded that the crossing lay ahead and the road goes straight. Railroad crossing ahead was the response of 101 of the student subjects. Both of these response types were categorized Level 2 (general locational information) and the summed frequency of such responses (103) appears in Table 4.

2) Sign C with curve arrow: Twenty-six student responses were of the type railroad crossing ahead and the road curves. Twelve students' responses were of the type railroad crossing ahead. Both response types were classified Level 2. The summed frequency of such responses appears in the Railroad Crossing Ahead category in Table 4.

TABLE 4

STUDENT SUBJECT RESPONSES (MOTION PICTURE TESTS)

TEST SCENE (Sign/Arrow Combination)	Correct Responses			Incorrect Responses	Total Sample
	Railroad Crossing	Railroad Crossing Ahead	Railroad Crossing Location		
Sign A, without arrow	132	164	-	-	296
Sign D, with vertical arrow	44	103*	17	22	186
Sign C, with curve arrow	8	38*	224	12	282
Sign B, with turn arrow	24	22*	190	19	255

SIGN A: Black on yelow, circular standard sign, MUTCD designation W10-1;
SIGN B: Black on yellow diamond with red 60^{0} X and white border;
SIGN C: Black on yellow diamond, with circular, red modified RXR symbol;
SIGN D: Borderless diamond sign with RXR symbol, red 60^{0} X with white border, yellow side quadrants and black in upper and lower quadrants.

Black arrows with signs B and C, and white arrows with sign D.

* Includes responses of the type 1) railroad crossing ahead, or 2) railroad crossing ahead and the road goes straight (vertical arrow),or the road curves (curve arrow), or the road turns (turn arrow).

3) Sign B with turn arrow: Fourteen (of 22) students responded that the railroad crossing was ahead and the road turned. The remaining eight merely responded that the crossing was ahead. The summed frequency (22) appears in the Railroad Crossing Ahead categorization in Table 4.

Table 4 reveals the following regarding the overall effectiveness of the four candidate sign/arrow combinations:

1) For Sign A, 164 of the 296 valid responses, 55%, displayed Level 2 understanding ("Railroad crossing is ahead"). This is almost identical to the figure obtained for the driver subjects, 56%.

2) For Sign D with a vertical arrow, 120 of 186 responses, 65%, were of Levels 2 or 3, a figure that was higher than that for Sign A at a statistically significant level ($p < .06$).

3) For Sign C with a left curve arrow, 262 of 282, 93%, were Level 2 or Level 3. This ratio is significantly higher ($p < .001$) than comparative ratios for either Sign A or Sign D.

4) For Sign B with a sharp right turn arrow, 83% (212 out of 255) of the valid responses were Levels 2 or 3, a better showing than either Signs A or D ($p < .001$).

In evaluating the relative effectiveness of the four candidate sign/arrow combinations in conveying Level 3 (specific locational) understanding to the subjects:

1) Sign A elicited no Level 3 responses. There is also no evidence, from scored responses or subject comments that Signs B, C or D would receive any Level 3 responses if presented without arrows.

2) The vertical arrow in Sign D yielded only 17 locational responses, 10% of the correct responses and 9% of all valid responses.

3) The left curve arrow in Sign C elicited 224 locational responses, 83% of the correct responses and 79% of all responses.

4) The sharp right turn arrow in Sign B resulted in 190 locational responses, 81% of the correct responses and 75% of all responses.

6.1.3 Conclusions (16mm Film Tests)

Conclusions drawn from the preceding discussion and the scored responses of both the driver and student driver groups (Tables 3 and 4), are as follows:

- There is no reason to exclude any primary signs from further tests based upon poor subject understanding of the railroad crossing message.

  Subject understanding of the fundamental railroad crossing message ranged from a high of 100 percent (312 of 312) for Sign A to a low of 89% (188 of 212) for Sign D. The technique of 16mm filming of the signs within the roadway context, without focusing or zooming on the sign proper may leave the viewer with a less than clear picture of the device to which he is responding. Subjects complained of this problem not only with <u>all</u> project prepared scenes, but also with the scenes appearing in the AAA film. There is also no question that unfamiliar (novel) devices will suffer more in terms of incorrect answers than those which are not new or novel. In the case of Sign D, the poor image problem was magnified by a sign containing considerable amount of black area.

- The vertical arrow, of the type tested, shows little promise for transmitting specific locational information, Level 3, of the crossing location with initial exposure, e.g., the crossing lies beyond or over the hill.

  The fact that only 17, all students, of 186 subjects expressed their receipt of the message that the crossing lies beyond the hill indicates such meaning would have to be learned with repeated exposure. How soon or how well this meaning could be learned is unresolved.

- The success of the vertical arrow in gaining subject expressed understanding that the crossing was AHEAD was unresolved.

  The purpose of the vertical arrow was specific locational information, Level 3, rather than Level 2 (AHEAD). Achievement of the Level 2 response, if conclusively demonstrated, is considered to fall far short of the goal, i.e., that the crossing lies "beyond a vertical sight distance constraint, i.e., a hill."

- Subject understanding that the curve arrow implied the crossing lay in or around the curve was excellent.

  The 239 of 302 (79%) who expressed the complex meaning that the railroad crossing lay in or around a curve is considered excellent, first exposure response to a novel sign incorporating a curve arrow. Such a high level initial response would seem to indicate a portion of those initially responding unfavorably would learn the meaning with repeated exposure. Receipt of this information and its ability to register a conscious warning was demonstrated by a driver subject who tabbed the information dangerous. Failure of subjects to deduce and express Level 3 responses was demonstrated by 337 responses to Sign A and Signs C and D, without arrows, none of which elicited a specific locational response. Most of these responses (312) were to Sign A however the researchers have no reason to suspect that Sign A was responsible for the lack of Level 3 responses. That is, without arrows or other information, none of the primary signs within the roadway context can be expected to supply Level 3 information.

- Subject understanding of the turn arrow was excellent.

  This conclusion was based upon the 75 percent correct response (190 of 255) to Sign B with turn arrow. The 190 correctly scored responses, Table 4, were of the type "railroad crossing beyond or around the turn ahead."

Other pertinent results of the film tests were:

1) Several driver subjects suggest the arrow would be better understood if placed in the lower rather than upper quadrant of the primary signs. This suggestion was followed up and a number of slides were made of primary signs with lower quadrant arrows similar to that shown in Figure 22. This arrow-placement option was made available to the students in the subsequent slide tests.

Figure 22

Arrow in Lower Quadrant

2) Eight of 16 driver subject responses to Sign A (standard) noted that more information was needed.

3) There were many driver subject suggestions pertaining to making the novel Signs B, C and D more readable. The interim project report (6) contains detailed subject comments.

6.2 Slide Tests

This section discusses the slide tests and presents the test results.

6.2.1 Driver Subjects

Procedure for Driver Subjects

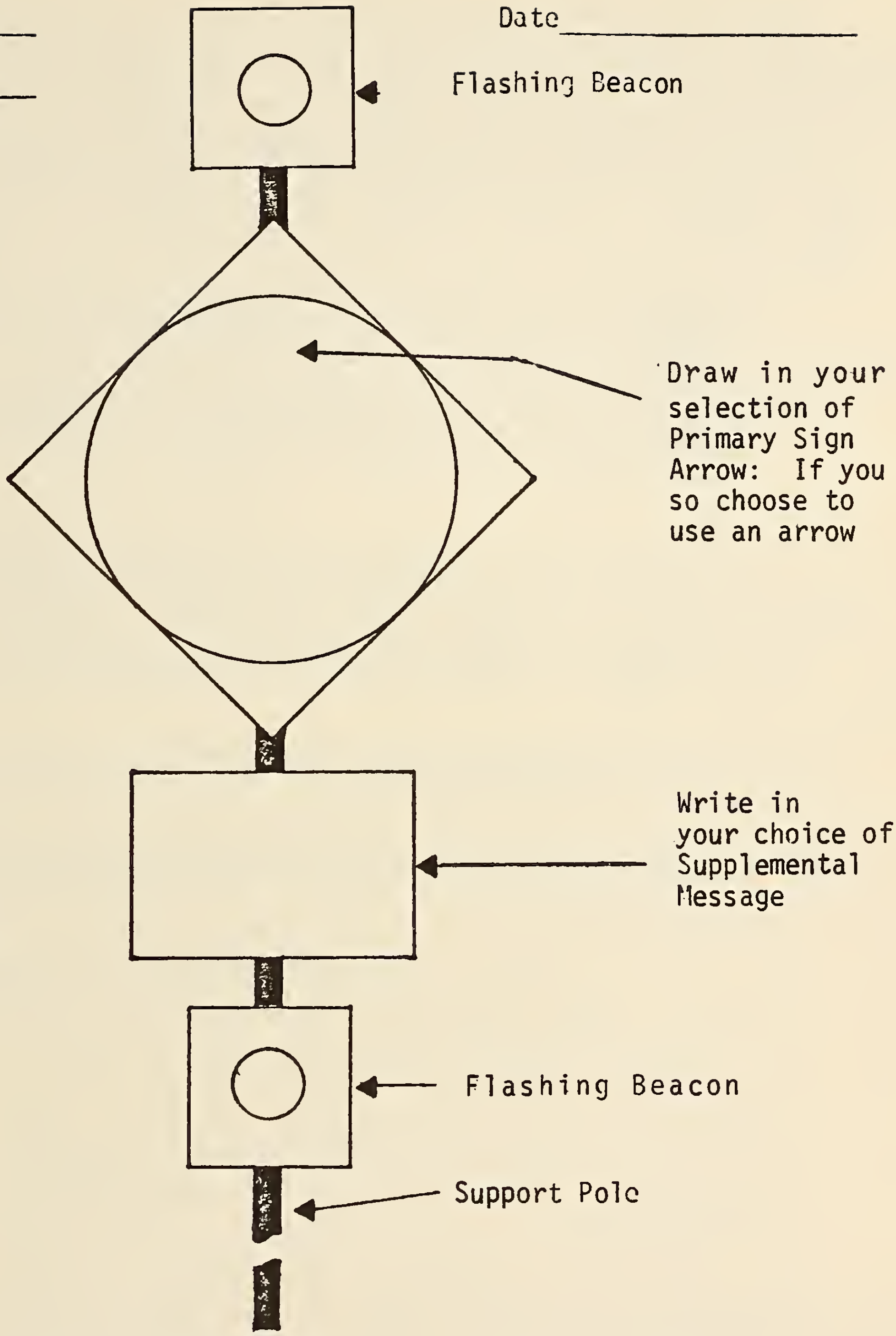
After a subject group had completed the motion picture tests, a break was taken and any questions answered about the subjects' reactions to the 16mm film scenes. The subjects were then told that the next session involved color slides, and that the specific purpose of the slide presentation was to study the relative effectiveness of several different types of signing configurations in warning a driver -- particularly, a driver who is unfamiliar with the area and not too good a driver at that -- of an upcoming railroad crossing that may or may not have a train on it or approaching it. The difference between passive and activated signing was explained, and, for the first time, the focus of the study on the development of train-activated advance warning devices was revealed. The subjects were told that there were three components of the AAWD's being studied, i.e., flashing yellow lights, a primary (fixed message) sign and a supplemental (variable message) sign, and that these components would be mounted on a post in the relationship shown on their subject response form (Figure 23).

The subjects were further told that they were to be shown slides of a number of different crossings, plus approaches to these crossings, and in each case were to assume that a train was at or approaching the crossing, and that all crossing warning devices were activated. Knowing this, they were to "compose" a sign (combination of primary and supplemental signs) that they felt would best serve this unfamiliar, not-too-good driver by providing the information he needed (in each case) to approach and traverse the crossing safely.

Each subject was given a coded set of color photographs of the four candidate primary signs (with and without arrows for Signs B, C and D) and the nine supplemental message panels. It was explained that the supplemental sign had a variable-message capability, so that the message it would display when a train was coming need not be the same message shown to a driver when no train was approaching the upcoming crossing. Further, subjects were told that if they felt none of the eight proposed supplemental messages was appropriate for the situation depicted, they could either choose the ninth option (blank sign) or, as a tenth choice, compose their own supplemental message (not to exceed four relatively short words in length). Each subject could either code his primary and supplemental selections or draw them in, or both, on the response form. In addition, the subjects were shown a brief film clip of a complete AAWD configuration mounted on a post to give them an idea of the actual appearance of the components in relation to one another and with the lights flashing.

Test Driver #_________ Date________________

Situation #__________



Write in
your choice of
Primary Sign
Letter

☐

Write in
your choice of
Supplemental Message
Number

☐

Test driver comments and/or additional information desired, if any: _______

____

____

Figure 23

Driver Subject Response Form
(Slide Tests)

The test session consisted of a series of slide presentations. Following each slide the subjects were asked to fill in a response form. Each presentation involved projection of a color slide showing an approach to a crossing, with the subjects being asked to assume that this "unfamiliar, not-too-good" driver is coming to a crossing along that particular approach road. The subjects also were asked to assume that a train is approaching the crossing, and that all at-crossing warning devices are activated. The subject's task, then, was:

1) to select one of the four candidate primary signs as being most applicable to the approach situation depicted and also to select an arrow, if he felt it would be of value. The subject's selected sign would be posted on the right shoulder of the approach road, along with the yellow lights and supplemental message plate, in a position pointed out in the scene by the experimenter.

2) to select one of the eight candidate supplemental messages (or a blank, or his own message) as being most appropriate in combination with the primary sign/arrow configuration selected.

The following five approach scenes were chosen for use, with primary emphasis on the first two:

1) The slide scene depicted a roadway curving out of sight around a horizontal curve.

2) The slide showed a curving roadway with the crossing located around the curve -- its location was pointed out by the experimenter.

3) The slide showed a roadway disappearing over the crest of a hill -- the crossing was out of the slide view (over the hill).

4) A tangent roadway approach was depicted with the crossing plainly visible in the distance.

5) The slide view depicted an intersection ahead -- the experimenter explained that the out-of-view crossing was beyond an intersection turn.

This set of five approaches evolved from the literature review and from a review of 32 possible situations that considered not only the approach but also the crossing itself, in terms of the number of tracks, angle of crossing, type of warning device at the crossing and state of activation for non-passive devices. Preliminary testing with naive subjects quickly revealed that number of tracks and type of warning device at crossing were subtleties that subjects would rarely perceive and that crossing angle was difficult to present clearly to the subject in an approach scene. It was decided, therefore, to concentrate on how variations in highway approach geometry influenced subject selection of an appropriate activated advance warning device, rather than compound the analysis by including variables whose effects could not accurately be assessed.

In preparing the subjects for the slide tests, a number of points were emphasized. The potential hazards of a crossing were explained, including those hazards present even when no train is coming and the crossing signals are not activated. Implied in the explanation was the idea that the AAWD should be conspicuous even when it is inactivated. The subjects were advised that the use of an arrow within the primary sign might be considered as too much information for the driver, and they were asked to consider this when making their decisions. When an approach roadway scene was shown to the subjects, the location of the proposed AAWD was pointed out and, when visible, the crossing location as well (Approaches 2, 4 and 5, above). When the crossing devices were not visible in the approach scene, the crossing was said to be "around the curve" or "over the hill" at a distance of approximately 750 feet (229m) from the AAWD location. Subjects were told that they had complete freedom in their "composing" of the AAWD, and could choose a completely different configuration for each approach, if they wished.

Results of Driver Subject Slide Tests

Of the 36 driver subjects, 33 responded in a consistent, discernible (and understandable) pattern. The remaining three subjects provided responses that were inconsistent and difficult to interpret; therefore, they were not included in the data analysis results presented in Tables 5 and 6.

Table 5 presents the subjects' primary sign selections by type of roadway approach and whether or not the crossing was visible in the approach scene. As indicated, seven subjects selected Sign A under all approach conditions, three selected Sign B and 15 selected Sign D. This means that since 25 of the 33 subjects made one primary sign their choice regardless of highway geometry, the selection pattern in Table 5 can be viewed as changes in choice of primary sign on the part of the remaining eight subjects. The selection pattern of these eight subjects was as follows:

1) For straight approaches with the crossing hardware in view, all eight subjects considered Sign A (the W10-1) best.

2) For straight approaches with a vertical sight obstruction, six subjects chose Sign A and one each chose Signs B and D.

3) For curved approaches where view of the crossing hardware was not obstructed, two subjects preferred Sign A, two chose Sign B and four thought Sign D to be most appropriate.

4) If the railroad crossing was either beyond an intersection turn or out of view around a curve, three of the eight subjects chose Sign B and five preferred Sign D.

Taking an overall view of Table 5, it appears that drivers do not consider the present standard (Sign A) adequate to meet their needs "across the board", i.e., in all types of crossing approaches. Sign D appeared to be the only sign that commanded strong preference for all approach conditions. Sign A was a relatively strong choice in straight approaches

Table 5

Primary Sign Selections
(Driver Subjects)

PRIMARY SIGNS	RAILROAD CROSSING APPROACH ROADWAY DESCRIPTION				
	Railroad Crossing in Driver View			Railroad Crossing Out of Driver View	
	Straight Ahead	Around Curve	Past Inter-Section Turn	Over Hill	Around Curve
Sign A	15	9	7	13	7
Sign B	3	5	6	4	6
Sign C	-	-	-	-	-
Sign D	15	19	20	16	20
TOTAL SUBJECTS	33	33	33	33	33

SIGN A: Black on yellow, circular standard sign, MUTCD designation W10-1;
SIGN B: Black on yellow diamond with red 60^{o} X and white border;
SIGN C: Black on yellow diamond, with circular, red modified RXR symbol;
SIGN D: Borderless diamond sign with RXR symbol, red 60^{o} X with white border, yellow side quadrants and black in upper and lower quadrants.

Note: Cell entries denote the number of subjects selecting a given primary sign for a given roadway approach. Seven subjects selected Sign A for all roadway approaches, three selected Sign B for all approaches and 15 chose Sign D for all approaches.

(whether the crossing was visible or not), but not where there was a horizontal sight restriction. Sign B was the third choice.

The subjects' selections of arrows to be employed with their selected primary sign are shown in Table 6. The cell entries in Table 6 show the frequency of selection of the specific arrow (vertical,curve or turn) for a given sign as well as the frequency of selection of the given sign as a function of the roadway approach description. The results indicate that the subjects feel arrows to be useful, particularly for the crossing approach involving a horizontal line of sight restriction. It is interesting that six of the seven subjects choosing Sign A for an intersection approach also chose arrows to go along with it, even though this option was not given to them in the set of color photos supplied to each. Post-testing dialogue with the subjects revealed that arrow usage with Sign A would have been greater if it had been an option. Subjects selecting the turn arrow for a crossing beyond an intersection turn drew it into their sign selection.

With regard to selection of messages to be placed on the changeable message supplemental sign, the 36 driver subjects responded to a cross-section of approach roadway scenes to give a total of 298 choices of activated messages for the five approach roadway types. Table 7 presents these choices. The results are rather complex; however, the most significant finding is that the "Train When Flashing" message was chosen most frequently for all roadway approaches, indicating that an explanation of the flashing lights is considered an important piece of information. (No discussion of the concept of "fail-safeness" was held with the subjects.)

At the end of each test session, the subjects were also asked to select messages to be used on the supplemental sign a) as the passive (i.e., non-activated) message on a changeable message sign, and b) as a permanent, non-changeable message, always visible to the approaching driver. The questionnaire used to obtain the subjects' responses (as well as other information) is shown in Figure 24. The driver subjects' choices of passive messages is shown in Table 8.

The subjects chose "Railroad Xing Ahead" most often for use as a passive message, whether the sign message was changeable or not. This message is redundant with the primary sign message, and its preference by the subjects probably reflects driver desire for simple signs as well as driver familiarity with similar signs in the past.

The "Train When Flashing" message makes little sense as a passive message for a changeable sign, and is not acceptable as a non-changeable message, because of the fail-safeness issue. Excluding "Train When Flashing" from consideration, the "Watch For Trains" was the second choice for both the passive and non-changeable message.

6.2.2 Students

Procedure for Student Subjects

One class of 27 driver education students was available for the slide tests following their motion picture tests. Because of the limited time period

Table 6

Arrow Selection Frequency
(Versus Primary Sign Selected)
(Driver Subjects)

PRIMARY SIGNS	RAILROAD CROSSING APPROACH ROADWAY DESCRIPTION: Railroad Crossing in Driver View			Railroad Crossing Out of Driver View	
	Straight Ahead (vertical arrow)	Around Curve (curve arrow)	Past Inter-Section Turn (turn arrow)	Over Hill (vertical arrow)	Around Curve (curve arrow)
Sign A	0/15	0/9	6/7	0/13	0/7
Sign B	2/3	4/5	6/6	3/4	5/6
Sign C	0/0	0/0	0/0	0/0	0/0
Sign D	9/15	17/19	20/20	14/16	19/20

SIGN A: Black on yellow, circular standard sign, MUTCD designation W10-1;
SIGN B: Black on yellow diamond with red 60^{0} X and white border;
SIGN C: Black on yellow diamond, with circular, red modified RXR symbol;
SIGN D: Borderless diamond sign with RXR symbol, red 60^{0} X with white border, yellow side quadrants and black in upper and lower quadrants.

Note: Cell entries reflect two frequencies X/Y. The quantity X is the frequency of selection of arrow usage with a selected sign for a given approach roadway. The quantity Y is the frequency of selection of the specific sign for the specific approach roadway description.

Table 7

Supplemental Message Selections
(Driver Subjects)

	Railroad Crossing Approach Roadway Description					
	Railroad Crossing in Driver View			Railroad Crossing Out of Driver View		COMPOSITE OVER ALL APPROACHES
MESSAGE	Straight Ahead	Around Curve	Past Intersection Turn	Over Hill	Around Curves	
Train When Flashing	8	25	11	12	24	80
Prepare to Stop	7	11	-	6	14	38
Railroad Xing Ahead	5	11	4	5	13	38
Stop Ahead For Train	4	10	2	7	9	32
Stop Ahead	4	10	3	4	8	29
Watch for Trains	-	4	7	3	3	17
750 Feet (Distance to Crossing)	3	4	-	2	4	13
Train Coming	2	4	3	-	4	13
Other Messages	3	8	8	7	12	38
NUMBER OF SUBJECT RESPONSES	36	87	38	46	91	298

Note: Cell entries are the frequency of subject responses.

QUESTIONS

1. What is your choice of message to be displayed when there is no train approaching the down stream crossing:

   ____

   Explanation of above answer: ______________________________

   ____

   ____

2. What is your choice of message to be displayed if it were not to be changed at any time, i.e., it is the same whether the sign is activated or not?

   ____

3. Do you feel that the arrows within the Railroad Advance Warning Sign are needed?

   yes ☐ no ☐ sometimes ☐

   Explain above answer: ______________________________

   ____

   ____

   ____

   ____

4. Please list any general comments you may have concerning this session.

   ____

   ____

   ____

Figure 24
Driver Questionnaire

TABLE 8

PASSIVE MESSAGE SELECTION FREQUENCIES

DRIVER SUBJECTS (SAMPLE SIZE: 36)

Messages	Passive Messages	Non-Changeable Messages
Railroad Xing Ahead	11	8
Watch for Trains	6	5
750 feet (Distance to Crossing)	4	-
Train when Flashing	3	7
Prepare to Stop	2	4
Other Messages	10*	12*
TOTAL	36	36

*Composite of a number of other selected messages each of which was selected no more than once.

available for testing, a simplified response form was developed (Figure 25) that emphasized multiple choice questions. Use of this form required that the students be made thoroughly familiar with the terminology on the form. This was done by using the approach roadway scenes shown to the driver subjects to explain the meaning of "horizontal and vertical sight distance constraints".

The slide tests were designed to elicit the following information from the students:

1) Which one of the four primary signs would they select for use at activated advance warning sites? They were asked to consider the ability of the sign to gain the driver's attention even when the lights are not flashing. They were also asked to consider daytime, nighttime and varying background conditions.

2) When, if ever, would they employ arrows within this sign? To do this, they were asked to identify the situation, roadway approach geometry and sight distance constraints under which an appropriate arrow should be displayed (if they felt that use of arrows was, indeed, <u>ever</u> necessary). They were also asked to identify, if one was used, whether the arrow should be located in the upper or lower quadrant of the sign.

3) Which supplemental messages, if any, would they employ under three different conditions? They were asked to select two messages, one for the activated state and one for the passive state - assuming a changeable message sign was feasible - to supplement the primary sign. They were also asked to select a third message (not necessarily different from the two - or one, for that matter - already chosen) for use in the event a non-changeable, permanently-visible message had to be used.

The students were also informed (as were the driver subjects) of the nature and purpose of the slide tests, with their emphasis on grade crossing safety. In order to prepare them to respond intelligently to the questions posed to them on their response form, the students were:

1) Shown a set of approximately 50 slides which depicted the four primary signs without arrows and with various curve and turn arrows (both right and left) and vertical arrows, located in both the upper and lower quadrants (except for Sign A, the W10-1). These slides showed the primary signs both with and without supplemental messages, under both daytime and nighttime conditions and different daytime backgrounds.

2) Shown a set of roadway approach scenes both with and without vertical and horizontal sight distance restrictions.

3) Shown a set of eight supplemental messages plus a blank (see Table 1) for composing their own "four short words or less" supplemental message.

1. When, if ever, would you use a directional arrow within the railroad advance warning sign?

   A. Never ☐

   B. When there is a vertical line of sight restriction — yes ☐ no ☐

   C. When there is a horizontal line of sight restriction — yes ☐ no ☐

   D. When there is both a horizontal and vertical line of sight restriction — yes ☐ no ☐

   E. When there is <u>no</u> line of sight restriction and

      a. The railroad crossing lies straight ahead — yes ☐ no ☐

      b. The railroad crossing is around a curve — yes ☐ no ☐

      c. The railroad crossing is around a sharp turn — yes ☐ no ☐

2. What is your choice of message (words) to be displayed by the advanced warning device when

   A. A train is at or near the crossing________________________________

   ____

   B. There is no train at or approaching the crossing_________________

   ____

3. If the same message were to be displayed by the warning device at all times, what message do you think is most applicable?_________________

   ____

4. Amongst the four primary signs, which sign do you feel would be best

   a. understood, and

   b. communicate the hazard that lies ahead, and

   c. be seen (not "tuned-out") by the driver, even though the lights may not be flashing.

A ☐ C ☐

B ☐ D ☐

(Check only one box)

Figure 25

Student Response Form (1)

4) Shown full-scale versions of the four primary signs in the classroom, as well as a demonstration of both 8-inch (20cm) and 12-inch (30cm) flashing yellow lights. This was done to give the students an appreciation of the actual size and appearance of these components of the AAWD -- an appreciation they were less likely to have than experienced drivers.

The four primary sign choices were projected on the screen together with their designated letter codes (A-D). Finally, those subjects who chose to use arrows within the primary sign were asked to indicate the preferred arrow location (upper or lower quadrant) on a separate form, shown in Figure 26. The two slides showing the four primary signs and supplemental messages were projected continually during the testing session.

<u>Results of Student Subject Slide Tests</u>

Of the 27 students, 25 made valid responses regarding primary signs. Of these:

1) five preferred Sign A (W10-1) as a primary message for general usage,

2) one preferred Sign B (Red X)

3) five preferred Sign C (red modified W10-1 symbol), and

4) fourteen preferred Sign D (black sign).

With regard to the students' attitudes toward arrows, Table 9 gives their opinions as to those conditions justifying the use of arrows. Two students indicated that they would <u>never</u> use an arrow within a primary sign (and both chose Primary Sign D); the remaining 25 subjects stated that an applicable arrow should be used at various times, depending upon roadway geometry. It is clear from the results that the students considered line of sight restrictions most important in warranting use of arrows within the primary sign. However, even when there is <u>no</u> sight restriction, and the crossing can be seen around a curve or sharp turn, more than 60% still chose to use an arrow. Regarding arrow location, all 27 students expressed opinions in this regard, and 20 of the 27 placed the arrow in the upper quadrant, the remainder in the lower quadrant. Finally, 16% (4 of 25) said the vertical arrow is needed.

Tabulation of the student responses to questions concerning supplemental messages is given in Table 10. Student selection of activated messages shows that the most preferred message was an explanation of the lights ("Train When Flashing"), followed by a description of what is happening ("Train Coming"), a redundant message ("Railroad Crossing Ahead") and an explanation of what is happening plus a directive as to what should be done about it ("Stop Ahead for Train"). The redundant message "Railroad Crossing Ahead" was the choice of 10 of the 27 students for the passive state and was selected equally with the non-fail-safe message "Train When Flashing" as the most preferred non-changeable message. Excluding the non-fail-safe message TRAIN WHEN FLASHING, WATCH FOR TRAINS was a second choice for the non-changeable message.

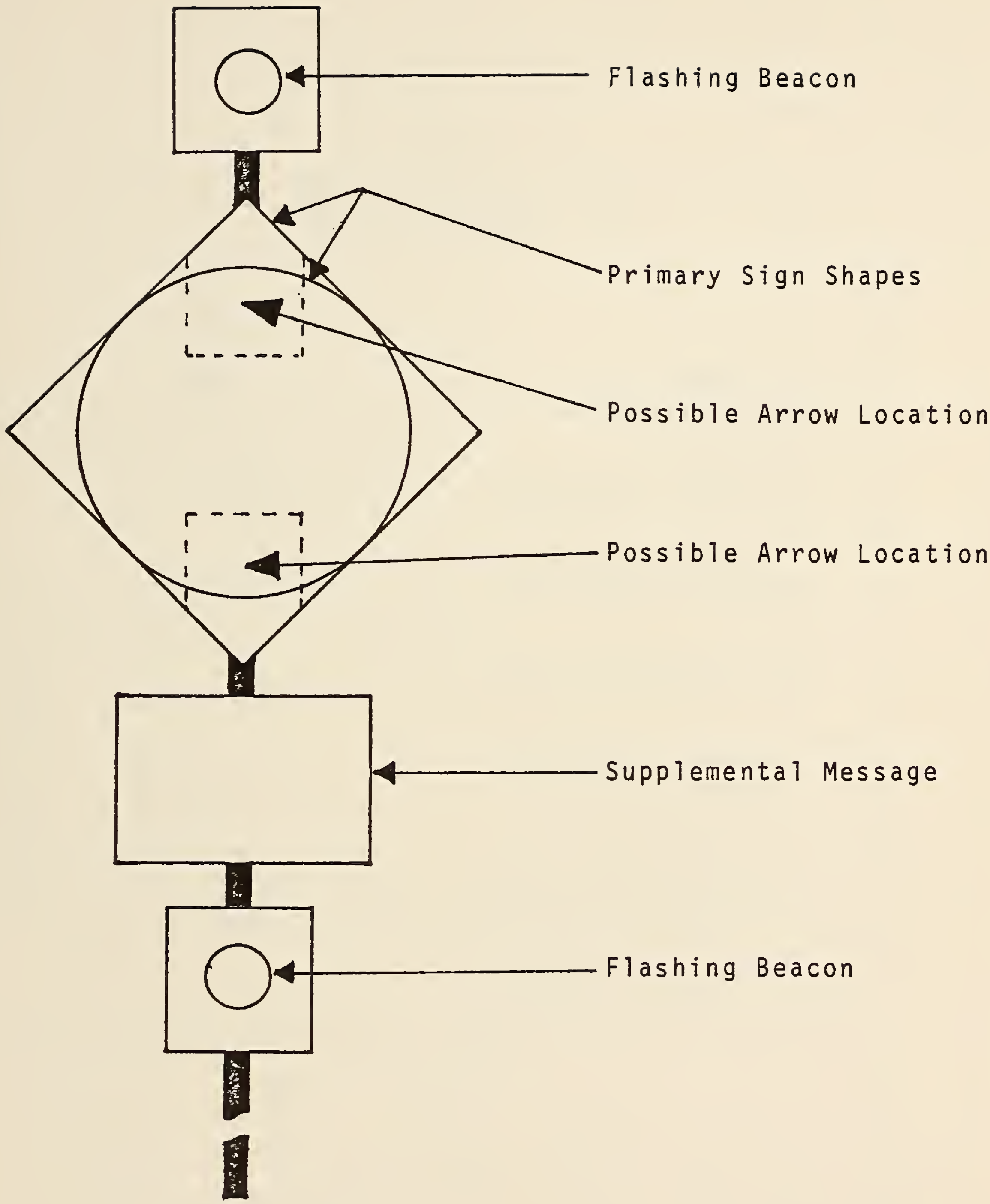


Figure 26

Student Response Form (2)
(Slide Tests)

Table 9

Use of Arrows in Primary Signs
(Student Subjects)

Conditions When An Applicable Arrow Should Be Used	Yes	No	No Answer	Total
1. Crossing lies straight ahead from the AAWD and can be seen.	4	19	2	25
2. Crossing lies around a curve from the AAWD and can be seen if the driver looks.	16	5	4	25
3. Crossing lies around a sharp turn from the AAWD and can be seen if the driver looks.	17	5	3	25
4. Crossing lies straight ahead of the AAWD location and is hidden by a vertical line-of-sight restriction.	18	7	-	25
5. Crossing lies around a curve from the AAWD and is hidden by a horizontal sight restriction.	21	4	-	25
6. Crossing lies over a hill and around a curve from the AAWD and is hidden by a horizontal and vertical sight restriction.	23	1	1	25

Table 10

Supplemental Message Selections
(Student Subjects)

Message	Changeable Message		Non-Changeable Message
	Activated State	Passive State	
Train When Flashing	7	1	8
Train Coming	5	-	-
Railroad Xing Ahead	4	10	8
Stop Ahead for Train	3	3	-
Prepare to Stop	-	4	-
Watch for Trains	2	3	3
Other Messages	6*	6*	8*
Total Responses	27	27	27

*Composite of a number of other selected messages each of which was selected no more than once.

6.3 Other Results of Indoor Laboratory Tests

To this point, the results of both the 16mm film tests and slide tests have been presented in terms of subject sign and arrow selection frequencies, or the degree or level of understanding expressed by the subjects in viewing nine primary sign and arrow combinations. These barren numbers do not reveal the information gleaned from subject verbal comments, post test discussions and analysis of patterns or trends which were seen to occur, particularly in subject choices of primary signs and word messages. Since this information was also given consideration in selecting signs for further tests, several pertinent points are summarized below.

1) Following the 16mm film tests subjects were informed as to the purpose of the project. In introducing the four primary sign candidates it was stated that primary Sign A (W10-1) was the existing standard sign. Unfortunately, this became an issue in two subgroups of drivers (comprising 12 of the 36 driver subjects). Despite efforts of the experimenter requesting that no verbal opinions be given lest they bias other subjects, there was one unrestrained individual in each group who found it necessary to voice his opinion relative to the W10-1 and the importance of maintaining a uniform standard sign. The sign selection frequency of the W10-1 versus the other three primary signs was higher with these 12 subjects than with the remaining 24 driver subjects. These responses (choices) were not excluded from the data since the need for uniform signing was also expressed in written comments, by 5 of the remaining 24 driver subjects. Furthermore, stating in the instructions to the subjects that Sign A was the standard could in itself bias the results.

2) Previously quoted driver results, Tables 5 and 6, indicate primary sign selection frequency and arrow selection frequencies were interrelated, and this was verified by post test discussions. An arrow option within the W10-1 was not offered to driver subjects. The impact of this constraint on primary sign selection is best viewed in the 7 of 33 subjects who chose the standard sign, without any arrow, when the crossing lay around a curve with a horizontal sight distance constraint (Tables 5 and 6). These same 7 subjects also chose the W10-1 when the crossing lay around an intersection turn ahead, yet 6 of the 7 drew in a turn arrow above, below or within the selected W10-1. The subject frustration that no such option was given was voiced during the tests, to which the experimenter instructed the subjects to draw their own sign if they didn't like the options. It is also reasonable to conclude that the 7 of 33 subjects (21%) considered uniformity to be the over-riding factor in their primary sign selection. There were more subjects (more than the 7) who selected the W10-1 in other approach roadway situations. This result is interpreted to mean that uniformity was also an important factor to a portion of the other subjects (26). However, they showed apparent willingness to sacrifice uniformity for a new sign when the arrow (vertical or curve) was more important than selection of the standard sign (see Tables 5 and 6).

So as not to cause the same frustration with student subjects who might select the W10-1, all four primary signs were said to have arrow options, i.e., there were no arrow constraints imposed upon the W10-1. However, there were no slide pictures shown to the students depicting arrows within the W10-1 since such pictures would clearly reveal how small the arrow would be and therefore possibly bias their primary sign selections. The lack of such pictures was explained as an inadvertent omission by the experimenter while assembling the materials for the class. The students were only allowed to select one sign for all approach roadway situations with 5 of 25 selecting W10-1. This represents 20% of the student subjects which is nearly identical to the previous 21% quoted for the driver subjects who selected the W10-1 over all approach roadway situations. Table 9 reveals that 21 of 25 and 23 of 25 student subjects chose arrows within their primary sign for a horizontal and combination horizontal/vertical sight distance limiting constraint, respectively. Under both of these two approach roadway situations, four of the five students selecting the W10-1 indicated they would use arrows within the sign.

Considering that only one primary sign type is feasible for all AAWD installations, except possibly in the case of the railroad crossing and closely spaced intersection, it is safe to say that roughly 80% of the 58 subjects would sacrifice the existing standard sign, W10-1, for a new sign which is capable of transmitting further information, i.e., employing an arrow within the sign. Although this is a small sample compared to the driver population, the researchers see no reason to expect the percent to change drastically with a larger sample.

3) There were a number of interesting results in subject responses to message selection as a function of approach roadway description. Subjects revealed that they established their own pattern, if any at all, and if there was any consistency between subjects, it would likely be revealed only in a very extensive analysis. Although the TRAIN WHEN FLASHING (activated) message was consistently selected with higher frequency than other messages over all approach roadway conditions, at no time was it selected by more than 30 percent of the driver or student subjects (Tables 7 & 10). The wide range of message selection for subjects is clearly shown in Tables 7 and 10. The foregoing, coupled with the wide variety of subject-volunteered messages of their own construction (tabled as "Other Messages") clearly reveals that while there may be a consensus "winning" selection, this should not be confused with agreement on the part of uninformed subjects - - a result considered in keeping with any group, informed or not, so long as individual preferences are permitted.

There were two messages, TRAIN WHEN FLASHING and RAILROAD XING AHEAD, which isolated two small subgroups of driver subjects. There were three driver subjects who selected the TRAIN WHEN FLASHING message as their choice for the activated message (over all roadway approaches), the passive message and the non-changeable message. By their choices, these subjects indicate that there is no need for a changeable message. A second group of four driver subjects also indicated no need for a changeable message by selecting RAILROAD XING AHEAD for the activated message (over all approach roadways), the passive message and the non-changeable message. It was concluded that the second group was stressing redundancy, since there were other subjects who selected the RAILROAD XING AHEAD message, but recognized that a crossing location lying beyond a 4-legged intersection turn ahead was not the best location for employment of this message, i.e., the crossing was not ahead unless the driver made the correct turn. There appeared to be no correlation between either of these sub-groups and the primary signs, or arrows, they selected.

4) Table 10 reveals that at least three students were either confused relative to the meaning of the "passive state" or unaware of driver's duties at railroad crossings and selected STOP AHEAD FOR TRAIN for the passive state of a changeable message. Included within the Other Messages category of Table 10 are other student responses which indicate lack of awareness of driver duties at railroad crossings, i.e., the subjects chose passive and non-changeable messages like STOP AHEAD and STOP LOOK AND LISTEN. The same confusion was evidenced in the driver subject tests (Table 8) where non-applicable messages were also categorized in the "Other Messages" category.

5) Two noteworthy message suggestions were made, both by students; TRAIN CROSSING AHEAD and SLOW-RAILROAD XING AHEAD. The latter is considered to contain too many letters for a 3x2 foot (.9x.6m) message plate. No additional investigation was conducted with the TRAIN CROSSING AHEAD message since the student tests marked the end of the message selection phase of the project.

6) The purpose of the slide tests was to obtain unconstrained subject feedback regarding their choices of primary signs, arrows and supplemental messages. In retrospect, identification of the W10-1 as the standard sign was the only piece of information given the subjects which might have biased their selections. Unconstrained by practicality, the subjects' choices (and their comments) were intended to give the researchers insight to more intelligent choices for field tests, i.e., practicality was the responsibility of the researchers.

7.0 OUTDOOR LABORATORY TESTS

7.1 Experimental Plan

The purpose of the outdoor laboratory tests was to measure driver responses to the candidate signs in a realistic, closed-course setting, and also to obtain some informal driver judgments on flashing lights. More specificially, the tests were designed to evaluate:

1) Driver understanding of the primary signs displayed in realistic locations alongside the roadway,
2) Driver understanding of the meaning of the flashing lights,
3) Perception-resolution distance of the sign symbols and the distance at which 2-, 3- and 4-word messages could be read,
4) Undesirable driver reactions, if any, to an activated device,
5) Any additional information gathered through driver subject responses to the full scale signs.

To accomplish the above, a 3.5-mile (5.6 km) course was laid out in a relatively untraveled roadway network within the confines of a military base. Within this roadway course were some existing side-of-the-road, post-mounted warning and regulatory signs, including curve signs, stop signs, speed limit signs and two "DIP" signs (W8-2). Interspersed among these permanent signs along the course were installed similar posts to hold the four primary signs (A,B,C,D), the latter three with supplemental message plates. One of the posts included the pair of yellow alternating signals.

In addition to the four primary signs, a diagrammatic sign was included in the tests. The diagrammatic sign had been excluded from the film testing since other research indicated that drivers found difficulty in comprehending these signs. Also, in light of the project budget constraints there appeared to be other signs available for less design effort which showed more promise for driver understanding. Design of the AAWD's for a railroad crossing with a closely spaced intersection was considered a special problem, although one of the film scenes solicited subject responses to a primary candidate sign and turn/arrow combination that was placed in advance of an intersection-turn approach to such a crossing. At the time of the outdoor laboratory tests, consideration was being given to the type of (passive) sign to be used at crossings with closely-spaced intersections. Addition of an already available diagrammatic sign to the outdoor tests to warn of such a condition was a simple task compared to the effort that would be required to design a new driver understandable diagrammatic sign. It was reasoned that the results obtained by adding a diagrammatic sign to the tests might prove helpful in the design of a more effective sign.

There were two days of testing and, to counter-balance sun position the placement of the signs was different on the second day than on the first. Also, for Signs B, C and D, arrow placement and supplemental message assignment changed from the first to the second day. Table 11 depicts the various combinations for the two days of outdoor testing.

Figures 27 through 31 show the appearance of the five signs in position for the second day's testing, with Sign B (Figure 28) appearing with the flashing yellow lights. The 12-inch (30 cm) lights, the largest and brightest commonly in use today, were chosen because they would be most likely to produce an adverse nighttime driver reaction, if any were forthcoming. There is no basis to assume that the driver attaches any different meaning to 12-inch (30 cm) lights than he would to 8-inch (20 cm) lights. Probably, he cannot tell the difference without paired comparisons, unless he cares to get close enough to estimate their size in inches. Figure 28 illustrates the fact that when the sign face is not illuminated by the sun, the approaching driver must be closer before he can read the sign clearly. (A standard lens camera and film are a poor representation of what is seen by the eye, and therefore magnify the readability problem of a poorly illuminated sign.)

Because the outdoor test plans included only a limited number of the driver subjects, it was decided to select only one example each of a 2-word, 3-word and 4-word message and to obtain a better estimate of the range in readability. The total driver sample was to be 24 subjects (of whom only 19 appeared and two of these were used to refine the testing procedure). The decision for selection of each sign was based upon which of the signs seemed to be most realistic in the closed course, although there also were reasons to exclude certain signs. The STOP AHEAD FOR TRAINS was selected as it was the only four word message. Among two word messages, the 750 FEET sign was excluded because it included digits. This left only the STOP AHEAD and TRAIN COMING messages for two-word signs. The closed-course included 5 railroad crossings but the military base had been closed to train movements for several years. Since the course also included two stop signs and because no trains would be seen, the STOP AHEAD message was selected for the two-word sign. Among three word messages TRAIN WHEN FLASHING could only be realistically displayed with the full scale AAWD, with lights. In that the researchers wished to solicit driver understanding of flashing light activation without a message explaining its meaning, the TRAIN WHEN FLASHING message was excluded. Due to reasons previously stated concerning realism, PREPARE TO STOP and RAILROAD CROSSING AHEAD were both viable 3-word candidate messages. RAILROAD XING AHEAD was selected because there were more railroad crossings than stop signs and because the 2-word STOP AHEAD message had already been selected.

Table 11

Primary Sign, Arrow, Message Plate & Light Combination
Outdoor Laboratory Tests

PRIMARY SIGN	DAY	ARROW	PRESENTED WITH FLASHING LIGHTS?	SUPPLEMENTAL MESSAGE
A	1	None	No	None
	2	None	No	None
B	1	None	No	Yes - Different one each day
	2	Right Turn Arrow In Lower Quadrant	Yes	Yes - " " " "
C	1	Vertical Arrow In Upper Quadrant	No	Yes - " " " "
	2	Vertical Arrow In Lower Quadrant	No	Yes - " " " "
D	1	Right Turn Arrow In Upper Quadrant	Yes	Yes - " " " "
	2	Right Curve Arrow In Lower Quadrant	No	Yes - " " " "
DIAGRAMMATIC	1	N/A	No	None
	2	N/A	No	None

Figure 27

Primary Sign A
Outdoor Tests

Figure 28

Primary Sign B
Outdoor Tests

Figure 29
Primary Sign C
Outdoor Tests

Figure 30
Primary Sign D
Outdoor Tests

Figure 31
Diagrammatic Sign
Outdoor Tests

7.2 Testing Procedure

Subject testing started at mid-afternoon each day, with all primary signs facing either east or west. This meant that the signs facing east were in the shade, while those facing west had sunlight on their faces. The afternoon testing ceased at dusk, with the last subject viewing all signs, facing either east or west, under low light levels. The east/west orientation of all five signs was changed on the second day so that each sign in turn, was viewed in both shade and direct sunlight. The nighttime tests were all conducted during darkness with the signs illuminated solely by the subject's headlight beams (both high and low beams were used during the testing).

Each subject drove the same automobile with properly adjusted headlights and was accompanied by the experimenter. The 3.5-mile (5.6 km) course was traveled one time by each driver who was told he would be taking a "leisurely" drive [at a "safe" speed of 20 mph (31 kph) or less] on a closed-course roadway, encountering some familiar and unfamiliar signs along the way. The purpose of the test was explained as being the evaluation of both sign and letter or symbol sizes as to their appropriateness, and that this information was needed to determine the size of signs needed on freeways, where speeds are high, as well as on residential streets, where speeds are low.

To get the desired information, the subject was told to respond to <u>all</u> shoulder-mounted signs encountered by:

1) Describing the sign as soon as he had any visual cues (color, shape, etc.) as to its presence, continuing the narrative process until he was able to express what the sign meant.

2) Describing when he could read the sign messages or clearly see the symbols, provided that he could guess the sign meaning earlier (based on other visual cues).

The experimenter explained that the roadway was marked in 100-foot (30.5 m) increments so that he could note the distances in advance of the signs at which the subject's comments were made. A tape recorder was on continuously to record subject comments as well as experimenter remarks. Each subject was asked to describe all or any part of a sign as soon as he could perceive anything. A total of 17 driver subjects, chosen in age and sex to represent the driver population, were tested over the two days -- seven during daytime hours, two at dusk and eight at night, with every subject seeing each sign. Based on their ability to read letters of known size, the approximate visual acuity of the subjects ranged from 20/20 to 20/60.

7.3 Results of Outdoor Laboratory Testing

Sign A (W10-1) - Based on observations of Sign A made under daytime sun, daytime shade and dusk (low level) illumination, the following may be stated:

1) Nine daytime subjects recognized the sign from distances of 600 to 1400 feet (183-427 m), with an average recognition distance of 851 feet (259 m).

2) According to post-test discussion, the greatest recognition distances belonged to those subjects who could not see the "R's", but were willing to state the sign meaning based on their perception of the "X".

3) Based on post-test discussions, no subject indicated that the circular shape of the W10-1 provided him/her with a clue to its meaning. This is in contrast to the 24-inch (61 cm) STOP sign encountered on the course, which was recognized at distances in excess of those given above for the 48-inch (1.2 m) Sign A, and which was credited by subjects as giving them both color (red and white) and shape (octagonal) cues.

When viewed at night, Sign A was recognized by eight subjects at distances ranging from 700 to 1000 feet (213-305 m), depending on whether low beams or high beams were used.

Sign B - The most prominent feature of Sign B was the red "X"; it was invariably the first element detected and commented upon. For example:

1) With the sign face in the sun, two of five subjects identified the X as red at a distance of 1750 feet (533 m). The X can be seen at a greater distance by those with 20/20 vision, but this was the maximum sight distance afforded the driver by the layout of the course.

2) At dusk, with the sun over the horizon in back of the driver the X was seen at 1500 feet (457 m) by the one subject who viewed it and noted the X as red at 1250 feet (381 m). When the sun was over the horizon behind the sign, the X was seen by the one subject viewing this situation as red at 600 feet (183 m), dramatizing the effect of veiling glare.

3) When viewed by two subjects in the daytime shade, the X was noted at 600 feet (183 m) and 1200 feet (366 m).

4) Eight nighttime subjects noted the X between 700-1200 feet (213-366 m) -- a range that includes both low-and high-beam, sign illumination. Although one of eight nighttime subjects saw that the X was red at 900 feet (274 m), the rest of the subjects did not note the red color of the X until they were 200 - 400 feet away (61-122 m). Noting the red X was sort of an afterthought by some subjects, i.e., at close range they were orally describing the message about the same time that they recognized the X was red.

With regard to the sharp right turn arrow that appeared on the lower quadrant of Sign B on the second test day, under shade and dusk conditions, three subjects noted the arrow between 225 feet (69 m) and 950 feet (290 m).

The overall crossing warning message of Sign B was received by one driver in daylight at 1500 feet (457 m), although he later admitted to the experimenter that he guessed at the meaning of the two "R's", which he could not see clearly until he was 900 feet (274 m) from the sign. With regard to the turn arrow used on the second day, two subjects received the message "railroad crossing around the turn" at about 700 feet (213 m), well in advance of their ability to read the message plate. At night, detection of the arrow, legibility of the "R's" and comprehension of the primary sign message generally occurred in the area of 200 to 600 feet (61-183 m) from the AAWD.

With respect to the legibility of the "R's" within the primary sign, shade conditions on the face of the sign reduced legibility distance about 30 to 35 percent below the legibility distance under direct sunlit conditions. At night, legibility distance decreased by 35 to 50 percent.

Sign C - Sign C was displayed with a vertical arrow in the upper quadrant on the first day, and the same arrow in the lower quadrant the second day. Of the 17 subjects viewing the sign, six identified the arrow as meaning "straight ahead" the first day, and only one the second day. Under direct sunlight, the red modified circular W10-1 symbol and its railroad crossing meaning was understood between 500 and 800 feet (152-244 m) by five subjects. Under daytime shade and dusk conditions, recognition of the symbol warning message (by four subjects) occurred at 300-475 feet (91-145 m). Under nighttime headlight illumination, the warning message was noted by seven subjects at between 200-400 feet (61-122 m), although one driver guessed the message at 600 feet (183 m) under high beams. Generally speaking, at night, subjects saw either the arrow or some red in the sign before they noted the sign's meaning.

Sign D - This primary sign was shown the first day with the two flashing lights and a right turn arrow in the upper quadrant. The second day, it was viewed with a right curve arrow in the lower quadrant (and no flashing lights). The findings were as follows:

1) Daytime recognition distances for the red X of the sign were provided by nine subjects and ranged from 800 to 1700 feet (244-518 m). The lower end of the range was at dusk and the high end under direct sunlight, with the shaded condition generally falling between the two.

2) The eight nighttime subjects indicated the red X was not normally seen as red until the driver approached within 200 feet (61 m), although one subject noted it was red at 600 feet (183 m).

3) With regard to the white arrows, under daytime conditions subjects noted them between 500 and 950 feet (152-290 m). This range corresponds to a lighting condition that ranged from dusk through shade to direct sunlight. The white arrows on a black background in Sign D were seen at a greater distance at night (350-900 feet, 107-272 m) than were black arrows on a yellow background used in Sign B, under both high and low beams.

4) The railroad crossing meaning of the primary sign was perceived at distances ranging between 400 and 800 feet (122-244 m) over night, dusk, shade and direct sunlight viewing conditions.

5) On the first day of testing, the integrated meaning of the sign and the right turn arrow (i.e., "a crossing in or around a curve ahead") was interpreted correctly without questioning the subject by two of six daytime subjects and one of three nighttime subjects. When asked the meaning of the total configuration (after driving by it), three of the remaining six subjects understood the crossing location clearly, and three were "not too clear" about its location. On the other hand, on the second day Sign D, with the right curve arrow in the lower quadrant, was clearly understood by all subjects viewing it (three daytime and five nighttime). Furthermore, subject understanding was verbalized prior to the reading of the supplemental message by seven of eight subjects despite the fact that no curve was visible following the sign.

Diagrammatic Sign - The diagrammatic sign shown in Figure 31 was understood by two of 17 subjects.

The railroad track symbol was recognized by one daytime subject, at 500 feet (152 m); however, most subjects recognized the symbol between 200-250 feet (61-76 m). Daytime, nighttime and high beams and low beams had no discernible effect on the recognition distance of 16 drivers. Although the double rail, five cross-tie symbol was far from optimally designed, it appeared that the symbol has too much detail and was initially guessed to be words by most drivers. A possible design improvement might be afforded by a single rail and cross-tie symbol.

The wide roadway portion of the symbol, Figure 31, was generally recognized as representing a roadway following recognition of the track symbol. Subject comments indicated that the recognition sequence was the result of confusion due to:

1) The small section of roadway extending beyond the track symbol, and

2) An initial subject impression, at greater distance, that the track symbol was writing.

These initial impressions gave rise to guesses as to the sign meaning that ranged from "church" to "airport". Although the roadway portions of the symbol would pose little understanding problem upon second exposure to the sign, the small section of roadway appearing below the tracks in Figure 31 was considered to be the major source of difficulty to long-range driver understanding. The two subjects who gained understanding, with some coaching from the experimenter, saw the sign when it was rotated 180° from its orientation in Figure 31. Elimination of this small section of roadway from the sign might aid in understanding, while presenting less than a complete roadway/track symbol. Addition of a thin yellow dashed line to the roadway symbol might also aid the driver. particularly in other orientations of the sign.

The results presented should not be taken to be definitive, as little effort was expended in design optimization. Likewise, the suggestions made were based upon comments from a few uninformed drivers and involved interpretation of these comments.

Supplemental Messages - The three supplemental messages were randomly assigned on each of the two testing days to Primary Signs B, C and D. Legibility distances obtained were as follows:

1) The "Stop Ahead" message was read:

   a) Between 275 and 600 feet (84-183 m), 390 feet (119 m) average, when viewed in daylight and dusk.

   b) Between 200 and 250 feet (61-76 m), 215 feet (66 m) average, when seen at night.

2) The "Railroad Xing Ahead" message was read:

   a) Between 200 and 250 feet (61-76 m), 225 feet (69 m) average, when viewed in daylight and dusk and,

   b) Between 175 and 225 feet (53-69 m), 200 feet (61 m) average, at night.

3) The "Stop Ahead for Train" message was read:

   a) Between 150 and 300 feet (46-91 m), 250 feet (76 m) average, in daylight and

   b) Between 250 and 400 feet (76-122 m), 320 feet (98 m) average, at night.

As can be seen from the foregoing, the supplemental message results were inconclusive. Meaning, length, number of words and familiarity of message are all variables that could influence legibility distance. From the data gathered, it is not possible to isolate the effect of number of words as had originally been hoped.

Activation of the Flashing Lights - Activation of the two 12-inch (30 cm) flashing yellow lights shown in Figure 27 did not produce any adverse driver reactions. To the experimenter's question as to the meaning of the flashing lights, roughly half of the subjects responded immediately (with varying degrees of confidence) and stated that the flashing likely meant that a train was coming. The remaining subjects wanted more information about the lights -- generally, whether or not the lights were always flashing. Several subjects indicated that they could have easily guessed the meaning of the flashing lights if they had seen the sign and lights (not flashing) at some previous time. Only one subject seemed to have no explanation at all for the meaning of the flashing lights.

7.4 Conclusions From Outdoor Tests

The manner in which the subjects responded to the signs, element by element as soon as they perceived each element, was considered more informational than one in which subjects would be requested to respond to the total meaning of the sign. To focus the experiment on "total meaning" would clearly limit the information to be collected as well as limit its point of collection to within a few hundred feet of the sign. Although instructing subjects beforehand that sign meaning was important, there were a number of subjects who focused on elements and responded to the total meaning of the device as an afterthought. There were several who had to be questioned as to the total sign meaning following their identification of the word message, particularly with Sign C and the vertical arrow. To drive the vehicle and verbally describe what was being seen produced a delay in the experimenter's recording of where it was seen. Likewise, it was also difficult to discriminate between where the subject-described elements were clearly seen and where they were correctly guessed. Greater response distances correlate with better visual acuity and willingness to guess while shorter distances correlate with lesser visual acuity and subjects who probably preferred to be more certain of their responses. In several instances the order in which the subject responded was not the order in which he/she saw the elements, e.g., the message was read and the subject said he had seen that the X was red earlier but had not noted so in his narration. The order of narration was generally as follows; sign, X, R's, railroad crossing, arrow, arrow and railroad crossing meaning and message; however, there were a number of exceptions to that order.

From the foregoing data, the following conclusions were drawn from the outdoor tests:

- The curve arrow, tested in Sign D, is a more simple symbol to integrate with an RXR message than the vertical arrow tested in Sign C.

  One subject failed to provide the integrated meaning with the curve arrow and subsequently responded correctly to the experimenter's question, "What does the entire device mean?" All 17 subjects were asked the same question of Sign C with the vertical arrow. Eight expressed confusion with the arrow displayed beneath the red-modified W10-1 symbol while 3 of nine were confused with the arrow above the symbol. Excluding the arrow in the bottom of the sign, these results (6 of 9) are poorer than what was achieved in the 16mm film tests of Sign B with a vertical arrow. The lack of promise of the vertical arrow in transmitting specific locational responses, "over the hill", could not be realistically tested in the course.

- The curve and turn-arrows were quite useful in providing crossing locational information to the driver.

  The turn arrow, which was employed solely in advance of a T-intersection turn did not convey its intended meaning quite as well as the curve arrow even when the latter was displayed on a tangent roadway section with no reinforcing curve lying in the driver's view ahead.

- Of the four primary signs tested, Sign B shows the most promise for maximizing the motorist's perception distance of the crossing warning message.

  In direct sun, the red X of Sign B was noted at maximum distance and described as red. In the shade, in dusk and during darkness, there is little basis to conclude its recognition distance was significantly greater than the X of the W10-1. As ambient light level decreased, the distance at which the X was recognized as red also decreased. Nighttime comments that the X was in fact red occurred at much closer range. The amount of black in Sign D clearly hindered discrimination of the X as well as its color.

- Red is a color having high target value.

  This conclusion is generally accepted and was clearly evident during the tests. In direct sunlight, the initial driver comment was about the color red (among those devices employing the color red) or included red in a description. Even at night, the much smaller red modified W10-1 symbol, Sign C, was noted as being something red in advance of driver recognition of the symbol.

- The amount of black in Sign D is excessive, and tends to distract some subjects' attention from the fundamental sign meaning in the daytime.

  Driver subjects volunteered numerous comments about Sign D upon passing its location, the majority of which verified the above conclusion. Two daytime subjects described it as attractive (conspicuous) as well as being difficult to "see" at a distance.

- There was clear evidence that the 2-word message STOP AHEAD was read at greater distance in daylight than RAILROAD XING AHEAD and STOP AHEAD FOR TRAIN. At night the four word message was read at a greater average distance than the other two messages. The only consistent result was that the RAILROAD XING AHEAD message was read at the least average distance during all ambient lighting conditions.

  Variance in subject visual acuity and inaccurracy in locating the exact distance at which the messages were correctly identified were likely responsible for the inconsistencies in comparative reading distances of 2-, 3- and 4-word messages.

- Based upon subject comments, no driver will be totally confident of the meaning of the flashing lights without additional information.

  The more astute drivers recognized that a pair of flashing yellow signals may not provide any more information than a continuously-flashing hazard warning beacon. However, there was strong indication that with repetitive exposure the meaning of activated flashing lights would soon be learned by most drivers.

8.0 FIELD TESTS

Following completion of the outdoor laboratory tests, the research program focused on field testing selected AAWD components in actual railroad highway grade crossing settings. The crossings to be employed in the field tests were, in the researchers' opinion, ones that had one or more approach roadway characteristics that warranted the activated advance warning treatments developed in the study. In particular, one of the following conditions was sought in each location chosen for field testing:

1) Physical obstructions to sight distance, either permanent or intermittent, such that when the at-crossing signals come into the driver's view there is insufficient distance to the crossing to permit adequate perception and reaction time (distance) plus braking time (distance) to bring the vehicle to a stop at the crossing.

2) A crossing approach roadway where at-crossing signals are located in the driver's peripheral vision as he views the roadway approach to the crossing. Furthermore the railroad signals have insufficient conspicuity within the driver's peripheral vision to alert him until he is too close to react and bring his vehicle to a safe stop.

3) An approach roadway which produces extended braking distances such that the crossing falls into situations 1 or 2 above, e.g., a downgrade.

8.1 Field Test Methodology

Planning for the field testing began with selection of the components of the AAWD's to be deployed, based on analysis of the outcome of both indoor and outdoor laboratory tests described in preceding sections. Next, measures of effectiveness to be employed in the testing were prescribed, given the constraints imposed on the testing by time, budget and the field environment. A specific test plan for each field location was developed based on the selected measures of effectiveness, the capability to stage traffic interventions such as crossing signal and AAWD activations as well as the ability to correctly locate the data collection equipment.

8.1.1 Selection of Test Devices

Selection of test devices to be deployed involved consideration of primary signs, supplemental message and the activation mechanism.

Primary Sign Selection

Results of the laboratory tests had strongly indicated that a fundamental railroad warning symbol together with a curve arrow would be understood by 79 percent of all drivers upon their first exposure. Considering the types of crossings which may warrant AAWD installation, the "critical" type would appear to be those crossings where there are physical obstructions to sight distance. Selecting this situation as a so-called "worst case", subject selection of primary signs revealed that alternative signs, B, C or D, were selected by 46 of 58 subjects. These results would appear to indicate that one or more of the new signs should be field-tested along with the standard W10-1.

The three new primary signs included only two methods of symbolizing the railroad crossing message. This is because Sign D is basically Sign B with the black border removed, the red X extended and the upper and lower quadrants shown in black rather than yellow. However, the symbol is identical -- two black R's spanning a red X.

In the critical situation of the crossing and approach roadway with horizontal sight distance constraints, 34 of 58 subjects, drivers and student drivers, chose Sign D for this crossing-approach roadway situation. Nevertheless, Primary Sign D was eliminated from the field tests for the following reasons:

1) Outdoor laboratory testing had demonstrated that the amount of black area in the sign was excessive and greatly reduced the distance at which the RXR message was received by the driver.

2) Sign D violates a present design constraint of the MUTCD which disallows a perceived change in basic sign shape when viewed in both daytime and darkness.

Therefore Signs A, B and C were selected for further testing, one at each of three different field site locations.

Message Selection

In developing the set of candidate messages (Table 1) the researchers sought a representative selection from among those in current use, those suggested by past research plus some new messages. The researchers desired to obtain uninformed preferences from subjects regarding the following choices:

1) The active message and the passive message for a supplemental message device having the capability of displaying two different messages.

   This two-message device was explained to all subjects. No constraints were imposed on the subjects' message selections. No information was given them regarding fail-safe messages and what the researchers classified as active messages versus what were classified passive messages (see Section 5.6). Finally, no explanation was given regarding a driver's duties at railroad crossings for fear of biasing their selections.

2) A single message which would be their choice for a fixed message in case it became too costly to provide a changeable supplemental message plate.

Activated Message Choice -- Over all crossing approach roadway types they examined, driver subjects chose the TRAIN WHEN FLASHING message in 80 instances out of 298 (27%). Students were shown a number of slides covering all approach roadway situations. They were then asked to choose one message that would indicate their preference as the best activated message, overall, for those situations viewed. Seven of 27 student subjects (26%) selected the TRAIN WHEN FLASHING message as their preference. Although not selected by half of the subjects, the message was chosen more often than alternative messages by both driver and student subjects. The researchers found no reason to disagree with this selection, provided it can be made failsafe. This means that the message TRAIN WHEN FLASHING would not be displayed at anytime there is a commercial power loss. Therefore the TRAIN WHEN FLASHING was selected as the preferred activated message for possible field testing.

Non-Changeable Message Choice -- The TRAIN WHEN FLASHING message was selected for this application by 15 of 63 drivers and students (see Tables 8 and 10). The message was eliminated from consideration as a non-changeable message because of the issue of fail-safeness in the event of commercial power failures.

The RAILROAD XING AHEAD message was selected by 16 of 63 combined student and driver subjects for the non-changeable message. This message was rejected for the following reasons:

1) The message employed with the W10-1 adds nothing to the fundamental sign meaning except the word AHEAD. In fact, the response AHEAD was expressed by 55-56% of those subjects seeing the W10-1 without message, in the 16mm film tests. This same message employed with other Primary Signs, B or C, with curve or turn arrows contains less information than the primary sign itself, and cannot be considered supplemental.

2) The purpose of the message component of the three-component device was to provide additional or supplemental information. The message plate component of the AAWD will add a minimum of 2 feet (.6m) to the height of the structure which increases the material costs of installation, considering such factors as wind loading, etc. The RAILROAD XING AHEAD message with its limited additional information could not be justified over a comparable device having no word message.

3) There were indications from the outdoor tests that the readability of the RAILROAD XING AHEAD message might require a larger message plate and increased letter size to be readable at distances comparable with other messages.

The driver and student subjects' third choice for a fixed supplemental message was WATCH FOR TRAINS, selected by 8 of 63 subjects. The message content of this selection was considered supplemental to the information of the primary warning sign and fail-safe in that it only implied that trains could be present. Therefore the WATCH FOR TRAINS message was selected for possible field test as a fixed message plate.

Passive Message Selection -- Reviewing the results shown in Tables 8 and 10, the frequency of selection of passive message by the 63 drivers and students was as follows:

1)	RAILROAD CROSSING AHEAD --	21
2)	WATCH FOR TRAINS --	9
3)	PREPARE TO STOP --	6
4)	750 FEET (Distance to Crossing)	4
5)	TRAIN WHEN FLASHING --	4
6)	STOP AHEAD FOR TRAIN --	3

Once again the RAILROAD CROSSING AHEAD message was rejected as a message that does not add any significant information. The subjects' second choice, WATCH FOR TRAINS, was selected for possible field testing as the passive message display of a 2-state changeable message plate.

Yellow Signals

Flashing signals used in the field tests were standard, off-the-shelf, 110V AC powered signal heads. Dependent upon the location of the field site, either 8-inch (20 cm) or 12-inch (30 cm) signals would be used. The larger heads were to be used in an area with significant background competition while smaller 8-inch (20 cm) heads were to be used in non-competitive backgrounds (5). Since all three field sites were located on rural highways without a competitive nighttime background, 8-inch (20 cm) signal heads were used at all three field sites.

8.1.2 Measures of Effectiveness

Any short term test is highly dependent upon selection of suitable measures of effectiveness (MOE's) which

1) Can be obtained covertly, lest they influence the driver and hence bias his response, and

2) Can be related to commonly-accepted, safety-oriented driver performance measures.

Vehicular speed and speed reduction are two commonly-accepted measures of driver performance. A preferable measure, and one that undoubtedly is more important, is a measure of awareness or level of awareness of the intervention being investigated. Unfortunately, such awareness data could not be measured very well in the field testing environment contemplated. For this reason, speed change at critical locations on the grade crossing approach roadway was designated as the primary MOE for the field tests. These speed changes were to be measured at selected points on the approach roadway using hand-held radars. The secondary measure for the field tests was to be the observation of brakelight activation together with rough estimates of when in the approach zone the initial brake application occurred. Generally speaking, but not without exception, earlier brakelight observation could be ascribed to quicker perception. The foregoing two measures were augmented by observational comments concerning driver behavior, e.g., braking on the approach, erratic maneuvers, looking behavior or any other overt action which might be used to classify a driver's total response to the AAWD.

8.1.3 Field Experiment Plan

In any test of a new device, it is extremely difficult to separate the "novelty effects" of the device from those effects which will be long lasting, particularly where limited resources do not allow for collection of long term data. It would have been desirable to test the AAWD's in a permanent installation; however, permanent installations take time to implement and cost considerably more than a temporary device which can be put up and taken down daily, and whose activation is controlled by field personnel. The costs associated with permanent site installations were beyond the budget limits of the project.

Testing at a permanent installation would have consisted of three data collection periods

1) Pre-installation data collection - "before data",

2) Post-installation data collection - immediately following installation -- novelty effect, and

3) Later data collection - "after data", following an operational interval to allow the novelty effect to wear off.

There appeared to be several opportunities to obtain a permanent installation for at least one of the devices; however, the necessary cost-sharing cooperation did not materialize.

A "Secondary" field data collection plan was devised for a temporary site installation. Without permanent electrical connection of the AAWD signals and interfacing their operation with railroad track circuitry, it would be cost prohibitive to manually operate the AAWD signals throughout a four-week interval necessary to remove novelty effect. There was, however, no reason that the primary sign and a fixed message plate could not be erected and left in place. This would allow motorists to become accustomed to passive components of the AAWD. The message WATCH FOR TRAINS was displayed on the fixed message plate. Without a permanent installation it was also impractical to install a changeable message device for the field tests. This was unfortunate since the non fail-safe message TRAIN WHEN FLASHING had been the consensus choice of the laboratory test subjects and could not be field tested under the conditions described.

Power from two 12-volt storage batteries was rectified to provide 110 volt AC power for the two 8-inch (20 cm) yellow signals during the field tests. A small radio transmitter and two receivers, one at the AAWD and one at the crossing control cabinet, provided separate remote control for activation for the AAWD and the railroad crossing signals.

Data Collection Plan

The field data collection plan included typical "before" and "after" data as well as additional data which might provide insight to the novelty effect of the AAWD . Under the plan, the AAWD (without the lights) would be erected following collection of the "before data", and then left in place for two to four weeks. At the conclusion of this period, the researchers would return, collect data regarding long term effects of the AAWD (without lights), then attach the lights and take additional data on the resulting driver responses.

The three- to four-week driver familiarization period allowed an opportunity to investigate any changes in driver response immediately following the emplacement of the primary sign and supplemental message ("novelty effect"). This period also allowed repetition of that investigation at a later time, prior to attachment of the flashing yellow lights, when any novelty attached to the appearance of a new sign post and signs would have worn off.

Thus, four principal evaluation periods were planned:

1) Prior to any installation (measures pre-existing conditions).

2) Immediately following installation of the primary sign and message plate.

3) Three or more weeks following Period No.2, with the primary sign and message plate still in place.

4) Immediately following Period No. 3, with lights added to the posts.

Within each of the four periods there were two test conditions of ambient lighting -- daytime and nighttime -- thereby providing eight tests. In addition, vehicle speed and speed change data were collected

a) under conditions of activation of both the at-crossing signals and the AAWD (when the yellow lights were installed in Period No.4), and

b) under conditions when the crossing signals and AAWD were both passive (i.e., under conditions of uninterrupted flow).

To establish a formal notation for the various data collection periods, conditions of ambient lighting and activation status, the field program at each site was organized into eight tests designated Test 1 through Test 8 with each test having a designation a or b, indicating whether the crossing signals and AAWD lights (when present) were activated or passive, respectively. Odd-numbered tests occurred in daytime; even-numbered tests at night. The complete notation of tests conditions is presented in Table 12.

Signal Activation

To acquire valid data on driver response to railroad signal activation requires a number of isolated, randomly-arriving vehicles, each in a specified position on the approach when the arriving train activates the crossing signals. To wait for these rare events with a train frequency of fewer than ten trains per day would require far more time than was available for the field tests. Therefore it was necessary to manually activate the crossing signals and AAWD when no train was present. This task was done using the small radio transmitter and allowed the research staff to activate, as well as turn off, both the crossing signals and the AAWD from a remote observation position. The impact of signal activation was focused on the target vehicle, which was isolated and speed-monitored through an activated signal(s) response zone. Furthermore, in case of an undesirable response, such as lack of slowing, the individual controlling the signals could turn them off, thereby avoiding a possible collision with the railroad gates or some other incident.

Signal Sequencing Plan

The plan for activation of the crossing signals and the AAWD (Tests 7 and 8) was a simple one. For each site a determination would be made as to what point on the target vehicle's approach to the crossing the crossing signals would be activated. That point would then be used

Table 12

Field Test Conditions

Test Number	Test Situation and Duration	Ambient Lighting	Activation a	Status b
1	Pre-existing Conditions First Field Period*	Day	Crossing Signals Activated	Passive**
2		Night	Crossing Signals Activated	Passive
3	Following Emplacement of the AAWD (without lights) First Field Period	Day	Crossing Signals Activated	Passive
4		Night	Crossing Signals Activated	Passive
5	AAWD Present (without lights) Second Field Period*	Day	Crossing Signals Activated	Passive
6		Night	Crossing Signals Activated	Passive
7	AAWD Present (with lights) Second Field Period	Day	Crossing Signals and AAWD Activated	Passive
8		Night	Crossing Signals and AAWD Activated	Passive

* The first and second field periods lasted up to one week each, and were separated by about four weeks.

** Signal lights inactivated.

throughout all tests (Subtest "a" for Tests 1-8) at that site. The plan also called for a sequential activation of the AAWD first and then the crossing signals for Tests 7a and 8a. These tests would then measure how effective the AAWD had prepared the driver for experiencing the activation of the crossing signals. This type of activation sequence is most important for daytime conditions, when the railroad signals are far less conspicuous than they are at nighttime. Prior research (5) had shown that during daytime conditions, the gate arm movement appearing in the driver's peripheral vision was highly conspicuous at distances where the lights were not visible. Therefore, it was the desire of the researchers that the conspicuity contribution of gate arm movement in the daytime be eliminated as much as possible.

There is no basic conceptual difference in signal sequencing between activated advance warning at railroad crossings and activated advance warning at traffic signals. There are numerous installations of activated devices placed in advance of traffic signals. A sequencing technique for railroad crossings is described in Section 9 which conforms conceptually to that employed at traffic signals. Therefore, the method of sequencing the AAWD and the railroad crossing device was not studied in the field tests.

8.2 Field Test Site 1 (Southern Pacific Crossing)

The first field site was a Southern Pacific crossing of a two-lane rural roadway located outside the town of Pleasanton, California; approximately 40 miles southeast of San Francisco. The crossing is located in the center of an S-curve portion of the winding county roadway. The north-bound approach to the crossing was determined to be the most critical and is complicated by a railroad grade separation (Western Pacific) which passes over the approach road within 200 feet (61 m) of the Southern Pacific grade crossing. The structure obscures the south-bound driver's view of the right-side-of-roadway-mounted signal lights and gates until he reaches a position roughly 500 feet (152 m) in advance of the crossing, although the back flashers are visible at a greater distance, about 900 feet (274 m) from the crossing.

The southbound roadway approach to the crossing is shown in Figures 32-38, while the layout of roadway, the grade separation and the grade crossing is depicted in Figure 39. Existing warning of the railroad crossing ahead is provided by a W10-1 sign, shown in Figure 35, 475 feet (145 m) in advance of the crossing. Other signing on the approach includes a W2-2 side road sign, 625 feet (191 m) from the crossing, and a W1-3L reverse turn sign 750 feet (229 m) in advance of the crossing. All warning signs are 30 inches (76 m) in size. (The W1-3L, used with a 30 mph (48 kph) speed advisory plate, should actually be a W1-5R winding road sign, warning of the first curve, which is right, not left.) The side road sign warns of an intersection located next to the crossing on the north side. The side road serves a private residence, but also has intermittent additional traffic. This additional traffic is created by

Figure 32
Driver View-1200 feet (366m)
(Southern Pacific Crossing)

Figure 33
Driver View-1000 feet (305m)
(Southern Pacific Crossing)

Figure 34
Driver View-800 feet (244m)
(Southern Pacific Crossing)

Figure 35
Driver View - 600 feet (183m)
(Southern Pacific Crossing)

Figure 36
Driver View - 400 feet (122m)
(Southern Pacific Crossing)

Figure 37
Driver View - 300 feet (91m)
(Southern Pacific Crossing)

Figure 38
Driver View - 200 feet (61m)
(Southern Pacific Crossing)

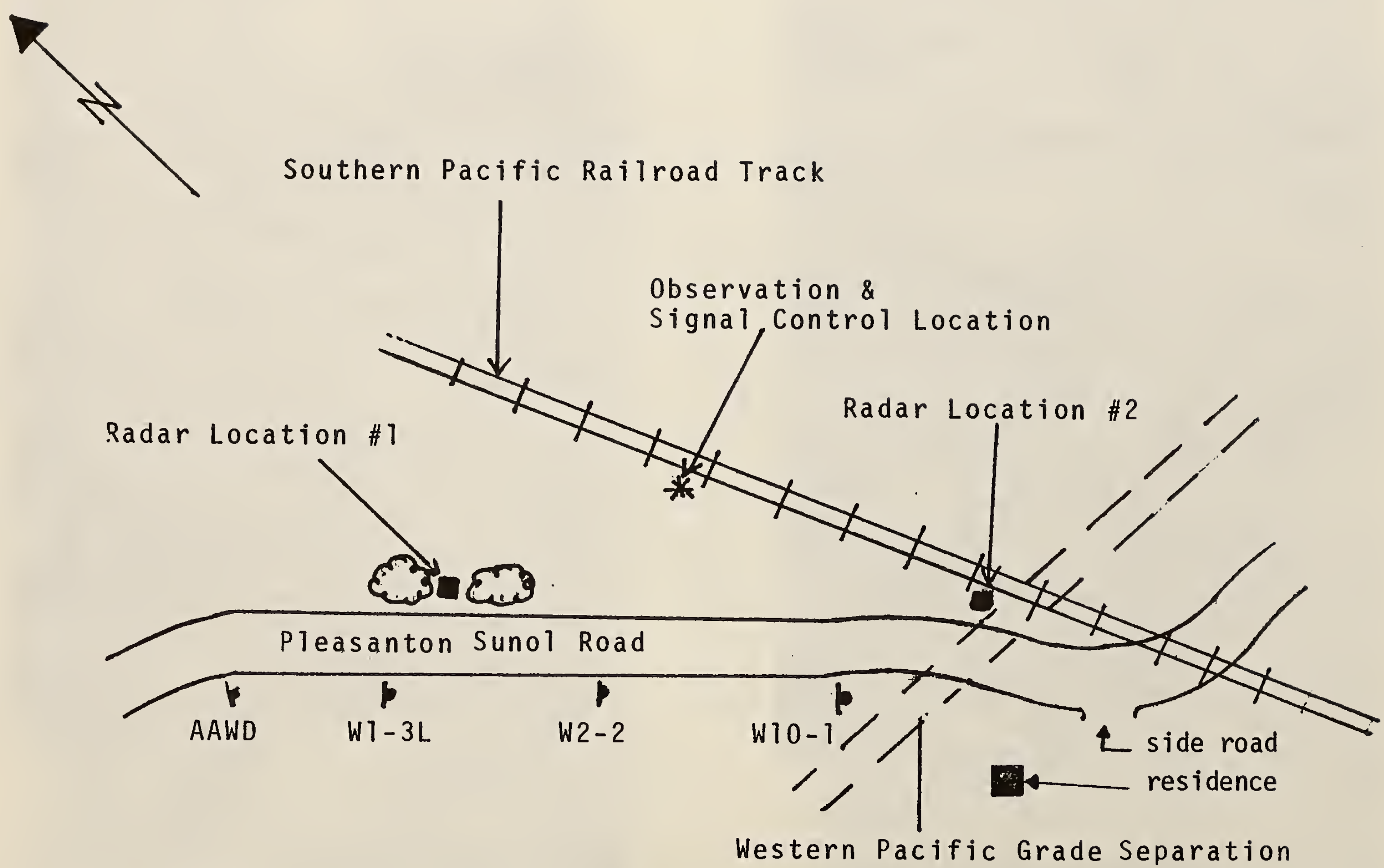


Figure 39
Plan View
(Southern Pacific Crossing)

drivers who do not know that the road is closed, i.e., it only serves the private residence. Posted speed on the county road is 45 mph (72 kph).

Large, 18 wheel truck traffic can constitute 35% of the total traffic during daytime, weekday hours, but such traffic is rarely seen during hours of darkness. Southern Pacific train activity over the crossing is normally two trains per day, one in the afternoon and one in the early morning (during darkness in winter months).

Prior to installation of the railroad gates in 1965, this site was experiencing four or more vehicle/train accidents per year with a train volume of 5-10 trains/day. Following installation of railroad gates there have been no reported vehicle/train accidents; however, there has also been a decrease in the number of train movements per day. A ten-year history reported 14 non-train-involved accidents in the crossing environment, four vehicle/vehicle accidents and 10 vehicle/object accidents involving eight injuries. This recent history did not include a fatality that occurred in the week before the field tests were started.

The winding roadway beneath the grade separation and over the grade crossing does impose sight distance constraints for the roadway users. These conditions, coupled with high vehicular speeds, provide for a potentially hazardous railroad crossing/roadway environment for non-train-involved vehicle accidents. Vehicular stops produced by activated railroad signals present a potential rear-end accident situation.

Placement of AAWD

The AAWD was placed approximately 900 feet (274 m) in advance of the crossing. Eighty-fifth percentile speed for southbound traffic 400-500 feet (122-152 m) in advance of the crossing was in the 50-55 mph (80.5-88.5 kph) range during daylight hours, and 2-3 mph (3.2-4.8 kph) higher at night. Therefore, using a 55 mph (88.5 kph) approach speed, zero grade, a wet pavement coefficient of friction (.23) plus a 2.5-second perception and reaction time, the safe stopping distance is approximately 640 feet (195 m) from the crossing. Maximizing the driver viewing distance of the AAWD, led to selection of a 900 foot (274 m) placement distance in advance of the crossing.

Following completion of Tests 1 and 2, the primary sign, a 48-inch (1.2 m) version of the W10-1, and the supplemental plate were mounted in a conventional right-side-of-road location as seen in Figure 40 and left in place for conduct of Tests 3-6. Two 8-inch (20cm) yellow signals were added, Figure 41, for conduct of Tests 7 and 8.

Activation of Signals

As previously described, field data collection was aimed at measuring the driver's response to the devices when he was isolated within the traffic stream, i.e., he was not in a car-following mode. When an isolated vehicle was selected for response evaluation the yellow signals

Figure 40

Primary Sign and Message Plate
(Southern Pacific Crossing)

Figure 41

Activated Advance Warning Device
(Southern Pacific Crossing)

of the AAWD were activated as he reached a roadway position 400 feet (122 m) in advance of the AAWD, 1300 feet (396 m) from the railroad crossing. Activation of the railroad signals took place when the driver reached a roadway position 550 feet (168 m) in advance of the crossing. At 550 feet (168 m) the driver view of the near-side* railroad signals were masked by the Western Pacific grade separation. Initial driver view of the activated, near-side railroad signals occurs at 500 feet (152 m) from the crossing.

8.2.1 Driver Speed Reductions

The experimental plan called for recording two approach speeds of vehicles. The incoming vehicle speed was recorded at a location 2000 feet (610 m) in advance of the crossing. This initial speed was the vehicle's free-running speed. At this location the driver had no visual cues indicating that there was a railroad crossing ahead. The second speed was taken when the vehicle was at a distance of 350 feet (107 m) from the crossing. At this latter distance, the driver had come under the influence of the AAWD as well as activated crossing signals. Deceleration, or speed reduction, refers to the difference in the vehicle's speed measured at the two roadway locations.

Analysis of the first week of testing, Tests 1-4, revealed not only considerable variance in initial vehicle speeds but considerable variance in the speed reductions, both with and without crossing signal activation. Driver speed behavior differences were so great that one could not discern from deceleration magnitude whether or not the crossing signals were activated, i.e., if it were not known. Therefore, data acquisition was modified during the second week of tests (Tests 5-8) to provide additional information. Approach vehicle speeds were also recorded at 900 feet (274 m) and 550 feet (168 m) from the crossing, when signals were activated. Collection of vehicle speed data when the signals were not activated included some sampling of the vehicle speed over the crossing. Appendix A, Tests 7 and 8, clearly reveals that AAWD activation produced speed reductions in the approach zone lying between 2000 feet (610 m) and 550 feet (168 m) from the crossing. This comparison can be made from separately tabled results depicting AAWD activation versus no activation of the AAWD yellow signals.

Daytime Speed Reductions

Previously described variances in driver behavior led to an analysis of speed changes (reductions) greater than or equal to 10 mph (16.1 kph). This reduction in speed applies to the two speed measurements taken at 2000 feet (610 m) and 350 feet (107 m) in advance of the crossing. Table 13 presents relative observed frequencies of speed reductions less than 10 mph (16.1 kph) versus reductions greater than or equal to 10 mph (16.1 kph). This analysis presents a coarse but revealing picture of the effect of the AAWD.

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* Right side of road location.

Table 13

Daytime Speed Reduction - (Signals Activated)
(Southern Pacific Crossing)

Initial Speed Category	Tests	Sample Size	Speed Change* ≥ 10 mph (16.1 kph) Yes	No
0 - 45	1	5	0	5
	3	5	0	5
	5	3	0	3
	7	1	0	1
46 - 55	1	7	2	5
	3	5	0	5
	5	10	2	8
	7	7	5	2
Over 55	1	5	1	4
	3	2	0	2
	5	7	0	7
	7	3	3	0
Composite	1	17	3	17
	3	12	0	12
	5	20	2	18
	7	11	8	3

* Speed change is the speed of the target vehicle at 2000 feet (610m) from the crossing minus its speed at 350 feet (107m) from the crossing.

All vehicle types are included in the table except large trucks.

1 mph = 1.6 kph

Despite the coarse analysis, the following statements may be made regarding statistical significance of results:

1) Speed reductions (composite category) greater than or equal to 10 mph (16.1 kph) are significantly more frequent with AAWD activation, Test 7, than without AAWD activation (and no yellow signals attached) for both Tests 3 and 5 ($p \leq .001$)* The identical statement can be made regarding Tests 7 and 1, where Test 1 described pre-existing site conditions.

2) For speeds greater than the posted speed limit, daytime speed reductions with the AAWD activated, Test 7, were significantly more frequent than when it was not, Tests 3 and 5 ($p \leq .001$). The same statement can be made comparing Tests 7 and 1, with $p \leq .002$.

Nighttime Speed Reductions

A tabulation of the results for nighttime Tests 2, 4, 6 and 8 appears in Table 14. There is an increased frequency of speed reductions greater than 10 mph (16 kph) for Tests 2, 4 and 6 compared to corresponding Tests 1, 3 and 5, respectively. The frequency comparisons illustrate the fact that crossing signal conspicuity is far less during the daytime than at night. Test 8 reveals an increased frequency of speed changes greater than or equal to 10 mph (for vehicle speeds greater than the posted speed) compared to Tests 2, 4 and 6.

The results of nighttime tests show that:

1) Composite speed changes, with both the AAWD and railroad signals activated (Test 8), were significantly more frequent than Test 2 ($p \leq .03$).

2) Test 8 speed reductions for vehicles over the 15 mph (72 kph) posted speed were significantly more frequent than Test 2 ($p \leq .05$).

The inability to make further statements of significant differences results from the small sample sizes. The magnitude of vehicle speed reductions can be seen in Appendix A.

8.2.2 Observational Comments

The experimental plan for this site called for sampling driver looking behavior at two positions: at the crossing with the railroad signals inactive and at the advance radar position when the signals were activated (Figure 39). Driver looking behavior at the crossing was non-existent, except for a van-type school bus driver who made a mandatory stop prior to traversing the crossing each day. During the first week of tests only one vehicle driver was observed looking to the left in search of an oncoming train before passing beneath the overcrossing. Driver attention was clearly fixed to the roadway ahead, i.e., negotiating the curving roadway and watching for opposing vehicle traffic.

* p values refer to significance levels using a Chi-Square Test (34).

Table 14

Nighttime Speed Reduction (Signals Activated)
(Southern Pacific Crossing)

Initial Speed Category	Tests	Sample Size	Speed Change* ≥ 10 mph (16.1 kph) Yes	No
0 - 45	2	4	1	3
	4	4	2	2
	6	4	0	4
	8	4	2	2
46 - 55	2	4	2	2
	4	5	1	4
	6	7	3	4
	8	7	4	3
Over 55	2	3	1	2
	4	3	2	1
	6	4	3	1
	8	6	6	0
Composite	2	11	4	7
	4	11	5	6
	6	15	6	9
	8	17	12	5

* Speed change is the speed of the target vehicle at 2000 feet (610m) from the crossing minus its speed at 350 feet (107 m) from the crossing.

All vehicle types are included in the table except large trucks.

1 mph = 1.6 kph

Driver looking behavior was sampled in the area of the AAWD following emplacement of the primary sign and message (Test 3). No looking behavior was discernible although there appeared to be periodic large truck deceleration near the device (detected by audible pitch change in the truck diesel engine). Radar coverage of this area of the approach was instituted for the remaining tests.

During daytime, brakelights seldom appeared within the 200 feet (61 m) of vehicle travel following the railroad signal activation (Tests 1, 3, 5) and were frequently seen to occur within 200-250 feet (61-76 m). This delayed braking indicates drivers were unprepared for daytime crossing signal activation when conspicuity of crossing signals is low, compared to nighttime. Installation of the AAWD signals produced two observable effects on drivers:

1) Their speed change was small until the crossing signals were activated and then brakes were quickly applied, within 200 feet (61 m),or

2) Their speed change (deceleration) was large prior to railroad signal activation with minimal brake pressure required to stop their vehicle within 550 feet (168 m) following crossing signal activation. That is, speed was lowered when the crossing signals were activated.

With few exceptions, nighttime crossing signal activation (Tests 2, 4 and 6) produced brakelights within 200 feet (61 m) following the point of activation. Quicker response at nighttime is due to the greater conspicuity of crossing signals at nighttime. Activation of the yellow signals of the AAWD at night, Test 8, produced a greater amount of early deceleration prior to activation of the crossing signals. The resulting lower speeds at 550 feet (168 m) from the crossing produced little difference in the location of brakelights following activation of the crossing signals.

The foregoing comments regarding brakelights exclude those drivers who elected to run through the activated railroad signals, an event which was not observed during Tests 7 and 8. Site testing was abruptly terminated when a large gravel truck rear-ended a vehicle stopped at the crossing. Damage was minor but the traffic tie-up was major since the truck was located straddling the centerline of the roadway. In addition,a number of near-collisions with the railroad gates occurred, a few including large trucks which approached the crossing in the direction opposite to that being monitored.

8.2.3 Site Conclusions

This site is an excellent example of a railroad crossing and curving approach roadway where sufficient safe stopping site distance is not provided by the railroad crossing signals (due to a permanent line-of-sight obstruction). Inattentive drivers and resulting delayed braking made data collection hazardous at the site during daylight hours.

Large truck speeds coupled with their unknown braking rate capabilities led the researchers to conclude that a significant percentage of the vehicles were traveling at speeds beyond their stopping capabilities. A number of these drivers likely knew that there was only one train/day during the truck operational hours. In the process of collecting data on the movement of southbound vehicles, seven large trucks traveling northbound became subject to crossing signal activation. Five of those seven trucks displayed erratic maneuvers in response to the lowering gates, indicating a lack of preparedness for the crossing. Research needs to be conducted relative to tolerable deceleration rates for large trucks. This information is important to specification of safe stopping sight distance (see Section 9).

Speed change variation among drivers dominated any deceleration which may have occurred due to the primary sign and message plate. Therefore, no conclusions can be drawn regarding possible novelty effects of the sign.

Activation of the AAWD was effective in producing earlier deceleration at greater distances from the crossing as well as preparing the driver for crossing signal activation. This was reflected by quicker brake response, particularly in daylight hours.

8.3 Field Test Site II (Santa Fe Crossing)

The second field site was a Santa Fe Railroad crossing of State Highway 58, located in the desert approximately midway between the two California communities of Mojave and Barstow. This high speed two-lane highway parallels the Santa Fe track, first on one side and then the other, with the crossing centered in the middle of an S-curve in the highway. The westbound approach to the crossing was determined to be the more critical of the two and, thus, was the approach chosen to test driver response to AAWD installation and operation. The speed limit on this highway was the maximum, 55 mph (89 kph).

Figures 42-47 present a driver's eye view of the westbound approach to the crossing ranging from 1600 feet (488 m) to 200 feet (61 m) in advance of the crossing. Signing on the approach includes a 3-foot (.9 m) MUTCD-specified W1-3R, reverse turn sign, approximately 1200 feet (366 m) from the crossing and two pairs of 5-foot (1.5 m) diameter W10-1's warning of the crossing ahead. The first pair (see Figure 44) is located some 625 feet (191 m) in advance of the crossing, one on each side of the road. The second pair (see Figure 46) is placed 300 feet (91 m) from the crossing.

There has been one accident at this site in the past three years. It was the result of a train just barely hitting the rear portion of the trailer of a large truck which ran through the railroad gates. Fortunately, no injuries were recorded. Train speed at the crossing is approximately 50 mph (80 kph). There are 10-20 trains per day, about equally split between daytime and darkness hours.

According to local Santa Fe signal maintenance personnel there is a railroad gate damage problem at the site. Although unpredictable, the repair of damaged railroad gates can be as high as once/week. Broken railroad gates occur more frequently during darkness than day.

Figure 42
Driver View-1600 feet (488m)
(Santa Fe Crossing)

Figure 43
Driver View-1000 Feet (305m)
(Santa Fe Crossing)

Figure 44
Driver View-800 Feet (244m)
(Santa Fe Crossing)

Figure 45
Driver View - 600 Feet (138m)
(Santa Fe Crossing)

Figure 46
Driver View - 400 Feet (122m)
(Santa Fe Crossing)

Figure 47
Driver View - 200 Feet (61m)
(Santa Fe Crossing)

A number of dual-wheel skid marks appear on the westbound crossing approach in Figure 47. One of these skid marks exceeded 700 feet (213 m) in length. This distance indicates either excessively high approach speed or an excessive braking distance of the dual-wheel vehicle producing the skid mark (see Section 9).

A daytime visual investigation of the viewing distance of the existing crossing signals revealed that, when activated, they are barely visible at a distance of 1000 feet (305 m) from the crossing (see Figure 43). This situation results in activated crossing signals inconspicuous to the driver who is looking down the roadway at this 1000 foot (305 m) distance. The crossing signal alignment provides maximum (daytime) brightness for the driver between 300 feet (91 m) and 400 feet (122 m) from the crossing. This can at least partially explain the daytime portion of the gate damage problem experienced at this site. This condition can present a problem in stopping a large vehicle traveling at or above the speed limit during daylight hours, particularly when a clear, uncluttered view of the right-side-of-roadway-mounted signal hardware itself occurs only at about 450 feet (137 m) from the crossing. The left-side-mounted back flashers enter an uncluttered central portion of the driver's cone of vision at about 525 feet (160 m) from the crossing.

California State Highway 58 carries a large amount of interstate truck traffic, particularly large trucks. Five surveys were taken of the traffic composition near the crossing site, with sample intervals (times) varying between 15 and 45 minutes in length. Table 15 contains the results of these surveys.

TABLE 15

Traffic Composition

(State Highway 58 - Near Santa Fe Crossing Site)

Time	Large Trucks*	All Other Traffic	Sample Size
7:00 a.m.	29%	71%	133
11:00 a.m.	30%	70%	171
2:00 p.m.	22%	78%	172
Midnight	61%	39%	75
2:30 a.m.	70%	30%	119

* Large trucks: Those having five or more axles and 18 or more wheels.

Placement of AAWD

The railroad gate damage problem, the number of large trucks and the speeds of large trucks at the crossing location resulted in emplacement of the AAWD 1000 feet (305 m) in advance of the crossing. The distance corresponds to a 2.5 second driver perception and reaction time for an approach speed of 60 mph (97 kph) plus a truck braking deceleration rate of 5 feet/sec^2 (1.5 m/sec^2), see Section 9.

The plan view of the Santa Fe crossing site is shown in Figure 48, which depicts the location of the AAWD. Following collection of the "before" data (Tests 1 and 2), Primary Sign B and the WATCH FOR TRAINS message were erected, as shown in Figure 49. The curve arrow points to the crossing location which lies to the right of the driver's view of the roadway ahead. The two 8-inch alternating flashing yellow signals, added for Tests 7 and 8, are shown in Figure 50.

Activation of the Signals

Manual activation of the crossing signals occurred when the driver reached a position 1000 feet (305 m) from the crossing, see Figure 43. As described earlier, activated crossing signals were just visible at this distance during daylight hours -- provided the driver looked in their direction.

The AAWD signals were activated, Tests 7 and 8, when the driver was 1800 feet (549 m) from the crossing or 800 feet (244 m) from the device itself. Therefore the time between AAWD and crossing signal activation was variable, dependent on vehicle speed. Sequencing of the activation of the two signals in a permanent installation would normally occur with time being a constant and distance traveled being variable, see Section 9. This procedure was not followed in the field tests for the following reasons:

1) The applicable time constant for each site would have produced more vehicle stops than the signal sequencing method selected. The data collection plan called for a minimum of 80 activations/per test site and it frequently required double this number to gain good data. The likelihood of producing rear-end accidents due to manual activation of the crossing signals would certainly increase as the number of vehicles required to stop was increased.

2) Fixing the location of driver response to activated signals would result in less roadway radar-coverage being needed to adequately record decelerations and also simplified the interpretation of the results.

8.3.1 Driver Speed Reductions

The primary radar position, shown in Figure 48, was located approximately 400 feet (122 m) from the crossing. From this position the radar operator was able to monitor approaching vehicle speed over a 2000 foot (610 m) range which terminated at a roadway location 500 feet (152 m) from the crossing.

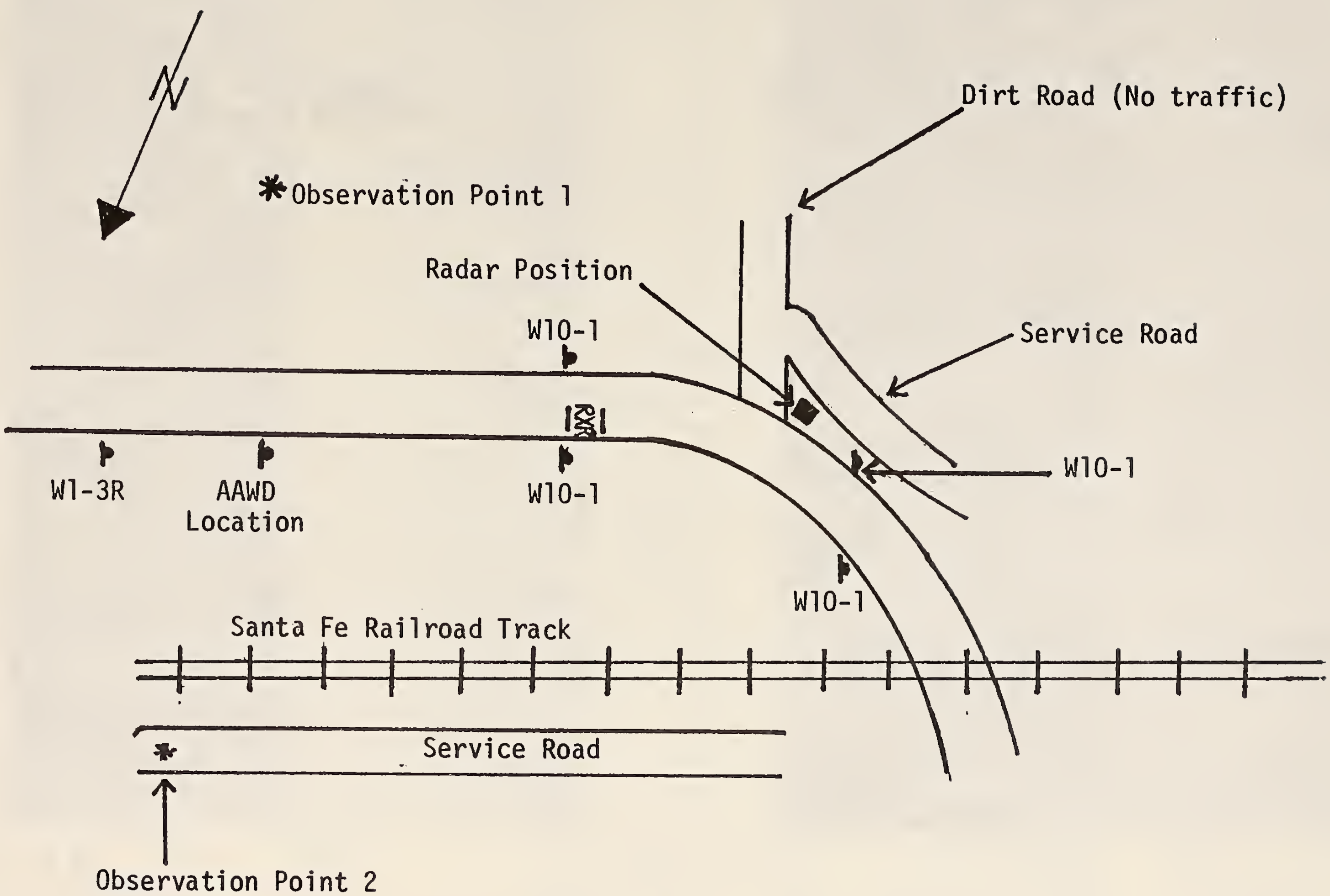

Figure 48
Plan View
(Santa Fe Railroad Crossing)

Figure 49

Primary Sign and Message Plate
(Santa Fe Crossing)

Figure 50

Activated Advance Warning Device
(Santa Fe Crossing)

A second radar, not shown in Figure 48 monitored incoming vehicle speed at a greater distance, i.e., 4000 feet (1.2 km) from the crossing. Incoming vehicle speed never varied over 1.0 mph (1.6 kph) between the distance of 4000 feet (1.2 km) and 1600 feet (488 m) of the crossing. That is, a driver's initial speed showed no variation greater than 1.0 mph (1.6 kph) over the next 2400 feet (732 m). Since the roadway surrounds failed to provide good concealment for the radar operator, the researchers monitored the truckers' CB radio channel for indications of possible sighting of test personnel by passing truck drivers. Discovery of the radar proved not to be a difficult task for the alert truck driver, due to his eye height (and his radar detection equipment).

Observation Point 1, Figure 48, was the position at which the crossing signals were manually (remotely) controlled. From this location, the person controlling the signals would watch the driver response and release the signals should he perceive the possibility of an undesirable incident. This position was also used by an observer who commented on vehicle brakelight activation as well as any other behavior considered relevant to description of the driver response. Only one daylight test, Test 1, was completed without the radar being visually spotted by passing truck drivers. The results of the radar tracking speeds, Tests 1, 2 and 4, appear in Appendix A. Discovery of the radar by passing truck drivers resulted in considerable chatter on the truckers' CB channel as well as a considerable reduction in speeds. Several attempts were made to conceal the radar location, including use of a remotely-placed, small tripod-mounted antenna. In each instance, however, passing truck drivers quickly located the radar and the results were the same -- slower speeds and CB radio broadcasting of the radar location. The timing of the data collection effort at the Santa Fe crossing site was coincident with long gasoline lines, rapidly rising fuel prices and trucking industry dissatisfaction with the 55 mph (89 kph) speed limit. Based upon CB communications following observations of the radar position, it was clear that irate truck drivers considered the radar just another threat to their livelihood.

Vehicle Speed Zone Timing

Although radar detection had been only a daytime problem, Tests 1, 2 and 4 had made it clear that driver detection of flashing railroad crossing signals was also a daytime problem. The activated crossing signals were clearly evident at great distances during hours of darkness.

An alternative method was developed to obtain driver speed response to activation of the crossing signals. This method was based upon stopwatch timing of vehicle passage time through a set of sequential zones of known length. Observation point #2 in Figure 48 was the position used to stopwatch time a vehicle passage through the set of roadway zones. A set of zone markers were set out, visible during both daytime and darkness. There were two approach zones defined for measuring speed response:

1) Zone 1: This zone was an 800-foot (244 m) approach roadway section directly in advance of the AAWD location, i.e., the roadway section between 1800 feet (549 m) in advance of the

crossing and the AAWD -- 1000 feet (305 m) in advance of the crossing. This zone was used to measure driver response to activation of the AAWD signals (Tests 7 and 8). The AAWD signals were activated as the approach vehicle entered this zone.

2) Zone 2: This 400-foot (122 m) zone conformed to the roadway section between the AAWD and a point on the roadway of 600 feet (183 m) in advance of the crossing. This latter location conformed to the center of an RXR pavement marking which was visible at night under headlight illumination. This zone was the driver response zone for activation of the crossing signals. Activation of the crossing signals took place as the approach vehicle entered Zone 2.

A third zone was used to describe the vehicle's initial speed. This zone was also 800 feet (244 m) in length and encompassed a roadway section between points 2600 feet (792 m) and 1800 feet (549 m) in advance of the crossing.

Relating the zone timing technique to radar collected data was done during nighttime when the radar operator was concealed by darkness. Calibration tests between radar collected data and stopwatch timing of zone travel times revealed the following:

1) There was a .1 - .2 second error in stopwatch timing of zone travel times.

2) Vehicle decelerations, normally occurring near the terminus of Zone 2, were rarely detected by the stopwatch timing method unless the radar-seen deceleration was 4 - 5 mph (6.4 - 8 kph) or greater.

Daytime Speed Reductions

Table 16 classifies speed change by zone (1 and 2) into two categories; Yes-a change (reduction) occurred, or No-it did not occur. Furthermore a change was said to occur if:

1) The passage time of Zone 1 was .2 seconds or more greater than the travel time recorded for the initial speed zone. No deceleration occurred if the Zone 1 passage time was less than .2 seconds more than the passage time of the initial speed zone.

2) A speed change was said to occur in Zone 2 if two times the passage time of Zone 2 was .2 seconds more than the travel time recorded in Zone 1. The two multiplier results from the relative lengths of Zones 1 and 2.

Using the calibration data and radar-recorded results from Test 1, a radar-detected speed change greater than 4 mph (6.4 kph) per zone was labeled as a speed change. Radar-recorded speed changes per zone less than or equal to 4 mph (6.4 kph) were tabulated as no speed change.

Table 16

Observed Frequency of Daytime Speed Reductions

Santa Fe Railroad Crossing
(Signals Activated)

Initial Speed Category	Test No.	Vehicle Type	Sample Size	ZONE 1 Speed Change		ZONE 2 Speed Change	
				Yes	No	Yes	No
55 mph	1	AO	1	0	1	0	1
	3	AO	-	-	-	-	-
	5	AO	1	0	1	0	1
and	7	AO	1	0	1	1	0
	1	PCU	2	1	1	0	2
Under	3	PCU	-	-	-	-	-
	5	PCU	5	1	4	2	3
	7	PCU	6	4	2	6	0
	1	AO	-	-	-	-	-
	3	AO	-	-	-	-	-
	5	AO	-	-	-	-	-
Over	7	AO	-	-	-	-	-
	1	PCU	9	2	7	1	8
55 mph	3	PCU	-	-	-	-	-
	5	PCU	8	0	8	0	8
	7	PCU	8	6	2	6	2
Composite	1	ALL	12	3	9	1	11
	3	ALL	-	-	-	-	-
Speeds	5	ALL	14	1	13	2	12
	7	ALL	15	10	5	13	2

PCU: Passenger Car Unit; Lt: Large Truck with 18 or more wheels; AO: All Other Vehicles; ALL: All Vehicle Types Except Large Trucks

ZONE 1: 800 foot (244m) roadway zone lying immediately in front of the AAWD location
ZONE 2: 400 foot (122m) roadway zone lying immediately following the AAWD location

55mph = 88.5 kph

Vehicles were classified into three categories:

1) Passenger Car Unit (PCU): a passenger or small pick-up truck

2) Large truck (Lt): any truck and trailer combination having 18 or more wheels and,

3) All Other Vehicles (AO): any vehicle other than a passenger car unit or a large truck.

Table 16 contains no large truck data. The researchers considered that daytime activation of signals using large trucks as the target vehicle would be taking undesirable risks in light of the incident occurring at the Southern Pacific crossing described earlier.

The composite speed category (Table 16) for all vehicle types occurring within the table reveals that:

1) The frequency with which vehicle speed reductions occurred in advance of the AAWD with AAWD signals activated (Test 7) was significantly higher than the frequency of deceleration in the same area (Zone 1) during Test 1 ($p \leq .01$) and

2) The same comparison between Tests 7 and 5 results proved significant at the $p \leq .001$ level.

The composite speed category, Table 16, also reveals that the frequency which which vehicle speed reductions occurred in Zone 2 (immediately following the AAWD location) was significantly higher in Test 7 than the frequency of deceleration in the same area for both Tests 1 and 5 ($p \leq .001$).

These foregoing results say that significant deceleration occurred in advance of the AAWD during the daytime (with activation) and furthermore this significant deceleration occurred in the succeeding 400 foot (122 m) interval when the railroad crossing signals were activated.

There is no data in Table 16 for Test 3. Test 3 was the last test conducted during the first week of final tests. The loss of this data was the result of visual observation of the radar by passing truck drivers. The technique of zone stopwatch timing was developed during the second week of testing (Test 5 - 8).

Table 17 contains daytime vehicle speed reduction data when there was no railroad crossing signal activation nor AAWD activation (Test 7). The table shows only one data point for Test 3, which was acquired prior to the truck driver discovery of the radar operator. Small sample sizes and insensitivity of the zone timing technique preclude any meaningful comparison between Test 1, 3 and 5, in regard to speed reduction effects of Primary Sign B and the WATCH FOR TRAINS message.

Table 17

Observed Frequency of Daytime Speed Reductions

Santa Fe Railroad Crossing
(Signals not activated)

Initial Speed Category	Test No.	Vehicle Type	Sample Size	Zone 1 Speed Change		Zone 2 Speed Change	
				Yes	No	Yes	No
55 mph and Under	1	Lt	-	-	-	-	-
	3	Lt	-	-	-	-	-
	5	Lt	-	-	-	-	-
	7	Lt	2	0	2	1	1
	1	PCU	1	0	1	0	1
	3	PCU	-	-	-	-	-
	5	PCU	1	0	1	1	0
	7	PCU	2	0	2	1	1
Over 55 mph	1	Lt	-	-	-	-	-
	3	Lt	1	1	0	0	1
	5	Lt	7	0	7	1	6
	7	Lt	3	1	2	1	2
	1	PCU	2	0	2	0	2
	3	PCU	1	1	0	0	1
	5	PCU	3	0	3	0	3
	7	PCU	4	1	3	1	3
Composite Speeds	1	Lt	-	-	-	-	-
	3	Lt	1	1	0	0	1
	5	Lt	7	0	7	1	6
	7	Lt	5	1	4	2	3
	1	PCU	3	0	3	0	3
	3	PCU	1	1	0	0	1
	5	PCU	4	0	4	1	3
	7	PCU	6	1	5	2	4

PCU: Passenger Car Unit; Lt: Large Truck with 18 or more wheels; AO: All Other Vehicles; ALL: All Vehicle Types Except Large Trucks

ZONE 1: 800 foot (244m) roadway zone lying immediately in front of the AAWD location
ZONE 2: 400 foot (122m) roadway zone lying immediately following the AAWD location

55mph = 88.5 kph

Nighttime Speed Reductions

Table 18 depicts deceleration frequencies by zone when the crossing signals were activated, Tests 2, 4 and 6. Test 8 results reflect deceleration frequencies when both the AAWD signals and the crossing signals were activated. Table 19 shows the same type decleration data collected on other vehicles when no signal activation occurred, i.e., neither crossing signals nor AAWD signals (Test 8).

Comparison of daytime and nighttime large truck decelerations without signal activation (Tables 17 and 19) revealed the following:

1) There were fewer trucks decelerating in Zones 1 and 2 than were holding constant speeds, both daytime and nighttime,

2) There was little difference in daytime deceleration frequencies of large trucks versus their initial speeds (over or under the speed limit) for both Zones 1 and 2,

3) There was a slight increase in deceleration frequencies of large trucks at night in both Zones 1 and 2, compared to daytime with higher frequencies correlating with higher speeds in Zone 2,

4) There is no trend seen in Table 19 which would indicate that Primary Sign B and the WATCH FOR TRAINS message (Tests 4 and 6) were producing more deceleration than Test 2 when the signs were not present. Addition of the inactivated yellow signals of the AAWD, Test 8, had no observable effect on large truck decelerations in either Zone 1 or 2.

The frequency of deceleration by zone with crossing signals and AAWD signals (Test 8) activated is shown in Table 18. The data reveals the following results:

1) Due to the high conspicuity of activated crossing signals at night the majority of vehicles decelerated more than 4 mph (6.4 kph) in Zone 2, Tests 2 & 4.

2) Tabled nighttime deceleration frequencies in Zone 2 reflect that little deceleration occurred -- this is not true as evidenced by brakelight observations. The data does reveal that the zone timing technique provided observer difficulties in locating the terminus point of the zone at night.

3) Despite the Zone 2 nighttime locational problems just described, the Test 8 results with both the AAWD and signals activated did produce so much actual deceleration in Zone 2 that it was properly classified by the stopwatch timing techniques.

4) Comparison of the Composite Speed Category reflects that speed reductions in Zone 1, with the AAWD activated (Test 8), occurred significantly more frequently than Zone 1 speed reductions in Tests 1, 2, 4 or 6 ($p \leq .001$).

Table 18

Observed Frequency of Nighttime Speed Reductions

Santa Fe Railroad Crossing
(Signals Activated)

Initial Speed Category	Test No.	Vehicle Type	Sample Size	Zone 1 Speed Change		Zone 2 Speed Change	
				Yes	No	Yes	No
55 mph and Under	4	Lt	1	0	1	1	0
	2	AO	-	-	-	-	-
	4	AO	2	0	2	2	0
	6	AO	1	0	1	0	1
	8	AO	2	2	0	2	0
	2	PCU	2	0	2	2	0
	4	PCU	4	0	4	4	0
	6	PCU	11	0	11	1	10
	8	PCU	5	4	1	5	0
Over 55 mph	2	AO	2	0	2	2	0
	4	AO	2	1	1	2	0
	6	AO	1	0	1	0	1
	8	AO	-	-	-	-	-
	2	PCU	10	1	9	8	2
	4	PCU	9	1	8	7	2
	6	PCU	7	1	6	0	7
	8	PCU	9	8	1	9	0
Composite Speeds	2	ALL	14	1	13	12	2
	4	ALL	17	2	15	15	2
	6	ALL	20	1	19	2	18
	8	ALL	20	18	2	20	0

PCU: Passenger Car Unit; Lt: Large Truck with 18 or more wheels; AO: All Other Vehicles; ALL: All Vehicle Types Except Large Trucks

ZONE 1: 800 foot (244m) roadway zone lying immediately in front of the AAWD location
ZONE 2: 400 foot (122m) roadway zone lying immediately following the AAWD location

55mph = 88.5 kph

Table 19

Observed Frequency of Nighttime Speed Reductions

Santa Fe Railroad Crossing
(Signals Not Activated)

Initial Speed Category	Test No.	Vehicle Type	Sample Size	Zone 1 Speed Change		Zone 2 Speed Change	
				Yes	No	Yes	No
55 mph and Under	2	Lt	6	1	5	0	6
	4	Lt	10	0	10	2	8
	6	Lt	1	0	1	0	1
	8	Lt	3	0	3	3	0
	2	PCU	1	0	1	0	1
	4	PCU	4	0	4	0	4
	6	PCU	-	-	-	-	-
	8	PCU	1	0	1	1	0
Over 55 mph	2	Lt	11	2	9	4	7
	4	Lt	5	1	4	1	4
	6	Lt	3	1	2	1	2
	8	Lt	1	0	1	1	0
	2	PCU	5	0	5	1	4
	4	PCU	4	0	4	1	3
	6	PCU	4	0	4	0	4
	8	PCU	-	-	-	-	-
Composite Speeds	2	Lt	17	3	14	4	13
	4	Lt	15	1	14	4	12
	6	Lt	4	1	3	1	3
	8	Lt	4	0	4	4	0
	2	PCU	6	0	6	1	5
	4	PCU	8	0	8	1	7
	6	PCU	4	0	4	0	4
	8	PCU	1	0	1	1	0

PCU: Passenger Car Unit; Lt: Large Truck with 18 or more wheels; AO: All Other Vehicles; ALL: All Vehicle Types Except Large Trucks

ZONE 1: 800 foot (244m) roadway zone lying immediately in front of the AAWD location
ZONE 2: 400 foot (122m) roadway zone lying immediately following the AAWD location

55mph = 88.5 kph

5) Test 8 with the AAWD and crossing signals activated produced significantly more frequent speed reductions in Zone 2 than did the crossing signals by themselves in Test 2 ($p \leq .01$), Test 4 ($p \leq .05$) and Test 6 ($p \leq .001$).

8.3.2 Observational Comments

For Tests 2, 4 and 6 only one instance of daytime brakelights was seen in the subsequent 500 feet (152 m) of vehicle travel following activation of the crossing signals. Daytime brakelights were generally first seen when the vehicle was within 250 - 350 feet (76 - 91 m) from the crossing. This would indicate that drivers were generally not perceiving the flashing railroad signals until they reached a roadway position having an uncluttered, down-the-roadway view of the flashing signals -- 400 - 450 feet (122 - 137 m) from the crossing (see Figure 46). On several occasions the lowering railroad gates were released so as to avoid the possibility of some minor incident resulting from the data taking effort. More than half the target vehicles exhibited delayed heavy braking caused by delayed perception of the flashing railroad signals. What is unknown is the relative contribution to perception of the flashing signals versus the lowering railroad gates. For a vehicle traveling 80 feet/sec (24 m/sec) the downward gate movement initiated when the vehicle was roughly 500 feet (152 m) from the crossing--downward gate movement was delayed following signal activation by 6 - 7 seconds.

Daytime activation of the AAWD (Test 7) produced deceleration and some braking in advance of the AAWD. Except for one driver, vehicle speeds were so altered by the AAWD and crossing signal activation that brakelight onset position tells very little about where the driver actually perceived the crossing signals were operating. The one driver who behaved differently ignored both the AAWD and crossing signals and ran over the crossing beneath descending gates. Based on travel time over 1800 feet (549 m) his average speed was roughly 70 mph (113 kph).

Nighttime braking, Tests 2, 4 and 6, was located within 500 feet (152 m) following crossing signal activation, with two exceptions, although neither vehicle had to perform heavy braking. Nighttime braking response to activated crossing signals occurred in the following ways:

1) A quick tap on the brakes, followed by brake release until the vehicle reached a point much closer to the crossing;

2) A quick tap on the brakes with the driver's foot remaining on the brakes (brakelight remains on) all the way to the crossing.

3) No quick brakelights, i.e., the vehicle may decelerate, but no brakelights were observable until the vehicle reached a point much closer to the crossing.

Addition of the yellow signals to the AAWD, Test 8, produced deceleration and braking in advance of the AAWD. Braking behavior following crossing signal activation was variable, i.e., some vehicles were traveling very slowly when they were 500 feet (152 m) or more from the crossing, while others had only decelerated a minimal amount (without braking) and brakelights came on immediately following crossing signal activation.

Driver looking behavior was sampled during conduct of daytime tests 3 and 5. There was no evidence that Primary Sign B and the WATCH FOR TRAINS message were creating a novelty, as would be indicated by increased driver looking behavior.

Detouring around lowered railroad gates was not an infrequent event and was observed on four different occasions during the field tests. In each case, however, this behavior was limited to daylight hours when drivers could clearly see the approaching train and better judge its distance from the crossing.

One slow moving large truck was used as a target vehicle during nighttime tests. Considerable braking noise occurred around 200 feet (61 m) from the crossing and the crossing signals were released. Deceleration of this vehicle was smooth and there was no evidence that the vehicle would not have stopped.

8.3.3 Site Conclusions

The ability of the AAWD (Tests 7 and 8) to produce an increased number of both daytime and nighttime decelerations in advance of the curve, as well as to lead the approaching driver to anticipate or look for the crossing signals, especially in the daytime, was clearly demonstrated through both observations and vehicle deceleration analysis at this site. It is unfortunate that the liability risks appeared too high too permit a test of the AAWD's effectiveness with large trucks as the target vehicles, since according to the local signal maintenance personnel, it is these vehicles which are the primary source of gate damage problems at the site. From conversations with drivers of some of these large trucks, such a device would be greatly welcomed at this site.

The State of California was planning installation of some type of AAWD at this site following completion of this research testing. There are two basic daytime problems at this crossing:

1) The crossing signals lie outside the driver's effective cone of vision when he is at an approach distance where his perception of the flashing signals should occur, to insure adequate braking distance.

2) Because of the narrow beam width of crossing signals, it is not possible to provide adequate signal brightness to the driver in the daytime when the signal is significantly offset from the driver's line of sight, and not oriented parallel to the approach path, as is the case here.

It is likely that the lack of crossing signal pre-warning and lack of a driver-understood clearance interval contributes to the nighttime gate damage problem at the site. Driver dilemma problems created by high-speed approaches to traffic signals have been thoroughly researched. The crossing signals, which provide <u>no</u> light display when inactive, present the driver with an even worse dilemma.

The potential for nighttime train/vehicle collisions due to insufficient nighttime signal conspicuity at this site is remote. The potential for daytime collisions, however, is considerably higher, but it should be nearly eliminated for the "compliant" driver with installation of an AAWD by the California Department of Transportation. The site is a good example of where there is a need for AAWD installation and there are no physical restrictions on line-of-sight.

8.4 Field Test Site III (Amador Central Railroad Crossing)

The third field site was a single track crossing of a rural two-lane highway. The crossing location is on State Route 88, roughly 45 miles (72 km) northeast of Stockton, California, and is at the base of a long 5 - 6 percent downgrade. Although there are only two to three daily train crossings, they do pose a stopping problem for large, heavily-laden trucks whose brakes are likely to be overheated near the base of the long downgrade.

The approach to the crossing is shown in Figures 51 - 57. There is a 600-foot (183 m) tangent roadway section directly preceding the crossing, and it is only on this final approach section that a vehicle driver is provided a full uncluttered view of the crossing signals positioned on either side of the roadway. In the daytime, the left side signal backflasher is barely visible, even if the driver is looking at it as he rounds the downhill curve (see Figure 53). At nighttime, the backflasher is clearly visible and conspicuous as the driver clears the line of sight restriction, approximately 1100 feet (335 m) from the crossing.

The ten-year accident history at this crossing shows only one vehicle/train accident, which resulted from a large, rock-laden truck being unable to perform a downgrade stop before colliding with the train at the crossing. According to discussions with railroad and law enforcement personnel, there have been intermittent, but persistent complaints from the trucking community that the railroad signals give insufficient warning. Speed of trains approaching the crossing is approximately 10 mph (16 kph).

According to California Public Utilities Commission personnel, there are long-range plans to upgrade the crossing warning system, including the addition of railroad gates at the crossing. Recent population growth in the surrounding areas has resulted in increased vehicular traffic volume, which presently is about 4700 vehicles/day near the site, with considerable seasonal variation.

Placement of AAWD

The plan view of the roadway and railroad crossing is shown in Figure 58. As shown in Figure 58 the existing passive advance warning for the crossing consists of a post-mounted W10-1 positioned on the right shoulder of the road at a distance of 370 feet (113 m) in advance of the crossing, along with the RXR pavement marking. The two radar positions measured downgrade vehicle speeds along the crossing approach.

Figure 51
Driver View - 2000 Feet (610m)
(Amador Central Crossing)

Figure 52
Driver View - 1600 Feet (488m)
(Amador Central Crossing)

Figure 53
Driver View - 1200 Feet (366m)
(Amador Central Crossing)

Figure 54
Driver View - 800 Feet (244m)
(Amador Central Crossing)

Figure 55
Driver View - 600 Feet (183m)
(Amador Central Crossing)

Figure 56
Driver View - 400 Feet (122m)
(Amador Central Crossing)

Figure 57
Driver View - 200 Feet (61m)
(Amador Central Crossing)

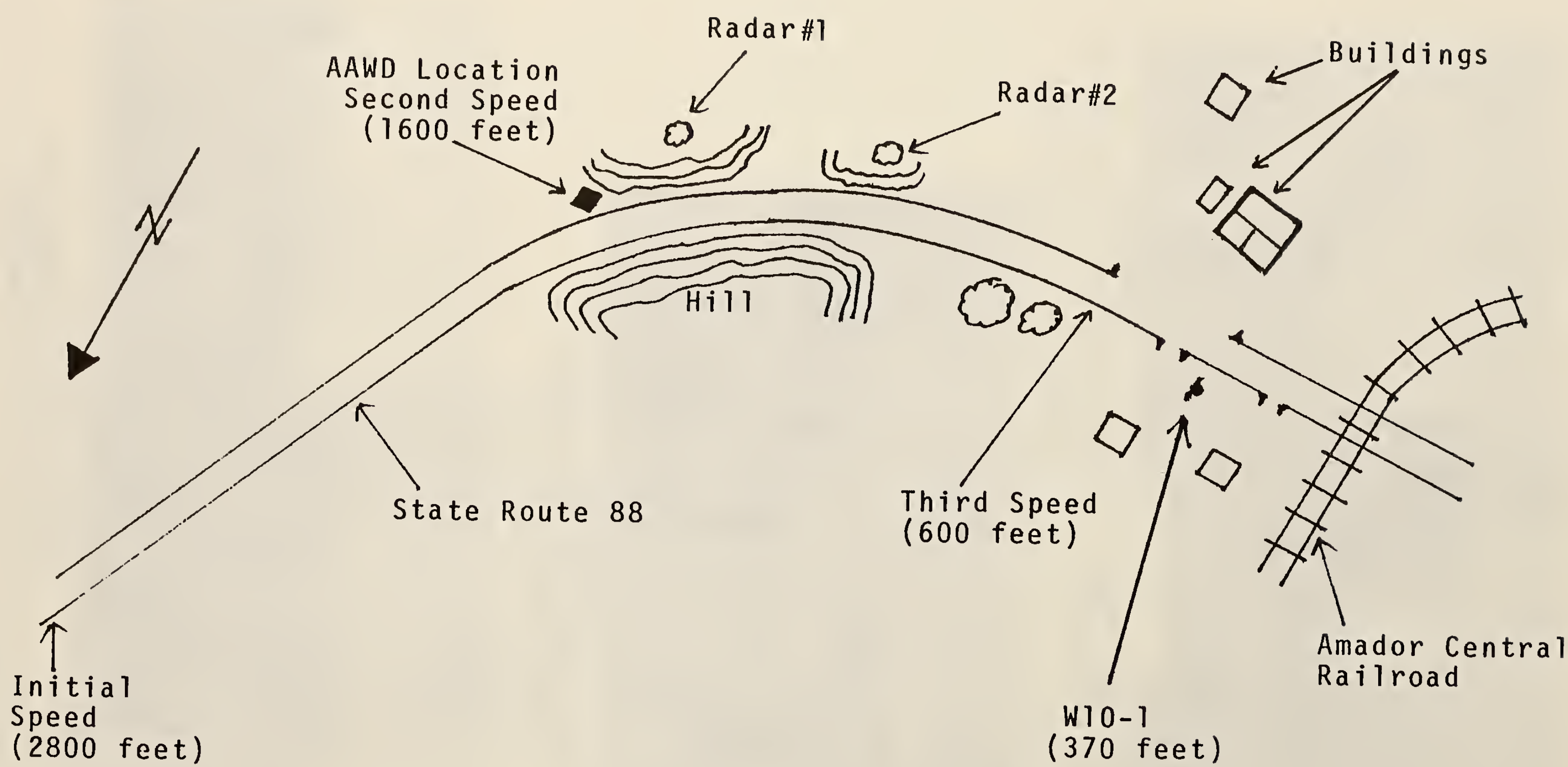

Figure 58.
Plan View
(Amador Central Railroad Crossing)

The AAWD was installed, as shown in Figures 59 and 60, on the left shoulder of the roadway, 1600 feet (488 m) from the crossing. This position was chosen to place the AAWD in the center of the approaching driver's line of sight. Conventional right side of roadway positioning would have required the device to be located roughly 1850 feet (564 m) from the crossing, to maximize the driver's approach viewing distance of the device.

Primary Sign C as seen in Figures 59 and 60 is 4 feet (1.2 m) in size. The red modified circular W10-1 symbol is 30 inches (.76 m) in diameter. The 3 x 2 foot (.9 x .6 m) supplemental plate contains the WATCH FOR TRAINS message having a 6-inch (15.2 cm) letter height. The right curve arrow uses an arrowhead from a 36 inch (.9 m) W1-2R and a shortened arrow stem from a 24-inch (.6 m) version of the W1-2R. This modification was compared by California Department of Transportation and project personnel to a 24 inch version of the W1-2R arrow in the same sign. It was this unanimous opinion that the modified arrow, Figures 59 and 60, greatly enhanced the legibility distance of the arrow component of the primary sign. It is estimated that the ratio of head size to stem width can be increased even more, with a corresponding increase in the legibility distance of the curve arrow.

Activation of Signals

The AAWD signals were activated, Tests 7 and 8, when the approach vehicle reached a roadway position 2400 feet (732 m) from the crossing or 800 feet (244 m) upstream of the AAWD location. Radar #1 (Figure 58) measured the approaching vehicle's speed at a roadway location 2800 feet (853 m) in advance of the railroad crossing. This speed was denoted as S_1. Radar #2 obtained approach vehicle's speed (S_2) at 1600 feet (488 m) from the crossing, a roadway position directly alongside the AAWD position.

Railroad crossing signal activation occurred as the approach driver reached a roadway location 1000 feet in advance of the crossing. The third speed, S_3, was also taken by Radar #2 as the receding target vehicle reached a position approximately 600 feet (183 m) in advance of the crossing. To obtain speeds at closer approach distances, the crossing required the radar operator to expose his location and his activities to other traffic, a risk which was considered unwarranted based upon problems that previously had arisen at the Santa Fe Railroad Crossing. However, during certain occasions, particularly at night, vehicle speed was monitored up to, over and beyond the crossing.

In addition to the speed measurements, supplementary data were to be obtained by observing the distance from the crossing of brakelight onset. Observation of brakelights occurred following the activation of the crossing signals as the approach driver reached a position 1000 feet (305 m) from the crossing, which is the maximum distance at which the activated crossing signals can be seen under daylight conditions. For those tests involving activation of the AAWD, i.e., Tests 7a and 8a, a target vehicle would be well past the AAWD location when the crossing signals were manually activated. Brakelight onset distance data were supplemented by the recorded comments of the test personnel regarding the target vehicle driver's response to the activated crossing signals. Furthermore, observations were taken of driver head movements at the AAWD location on a limited sampling basis.

Figure 59

Primary Sign C
And Supplemental Message
(Amador Central Crossing)

Figure 60

Activated Advance Warning Device
(Amador Central Crossing)

8.4.1 Driver Speed Reductions

The test sequence followed the schedule previously described in Table 12, namely:

> Tests 1 and 2 were conducted during the first test period without any modifications or additions to the site.
>
> Following conduct of Tests 1 and 2 the Primary Sign and the supplemental WATCH FOR TRAINS message were installed, Figure 58, and Tests 3 and 4 were conducted.
>
> Four weeks after Tests 3 and 4, with the Primary Sign C and the supplemental message having remained in place in the interim, Tests 5 and 6 were conducted.
>
> Following Tests 5 and 6, the yellow signals were installed to complete the AAWD (see Figure 60), and Tests 7 and 8 were conducted.
>
> As previously described, odd-numbered tests refer to daytime tests while even-numbered tests were conducted at night. An additional notation a or b is added to the test results reported in this section where a denotes tests where signals were activated and b denotes tests conducted when signals were not activated.

Presentation of the results of field testing the AAWD's has been organized according to the types of vehicles encountered and also according to behavior under daytime and nighttime conditions.

Large Truck Behavior

Based upon earlier experience with large truck behavior, and the researchers' desire to avoid any undesirable incidents resulting from manual activation of the signals, no data was collected using large trucks as target vehicles for signal activation.

Speed profile data for large trucks approaching the crossing in daytime without signal activation are shown in Table 20. Although the posted downgrade speed for trucks is 45 mph (72 kph), approximately half of the large trucks sampled had initial speeds in excess of 50 mph (80 kph) entering the downgrade approach to the crossing. It was noted, however, that there was a high degree of correlation between truck speed and how heavily the truck was laden. With a few exceptions, more heavily laden trucks were relatively slower initially, accelerated slightly in the first speed comparison zone and held a more uniform speed through the second zone. Some braking was observed in the first zone for heavy trucks, with additional braking for these same trucks occurring within 1000 feet (305 m) of the crossing. Speeds near the crossing were close to or slightly higher than "initial speeds" measured at 2800 feet

Table 20

Daytime Speed Profile Data for Large Trucks
Amador Central Railroad Crossing

			Frequency of Occurrence of Observed Speed Changes				
			Zone 1: S_1 {2800 ft}, S_2 {1600 ft}			Zone 2: S_2 {1600 ft}, S_3 {600 ft}	
Initial Speed (S_1)	Test No.	Sample Size	Acceleration $S_1-S_2 \leq -2$ mph	No Change $\lvert S_1-S_2 \rvert \leq 1$ mph	Deceleration $S_1-S_2 \geq 2$ mph	No Change $\lvert S_2-S_3 \rvert \leq 1.0$ mph	Deceleration $S_2-S_3 \geq 2$ mph
0-50 (mph)	1b	4	1	3	-	3	1
	3b	3	2	1	-	2	1
	5b	4	1	2	1	4	-
	7b	5	1	4	-	2	3
Over 50 (mph)	1b	5	-	4	1	4	1
	3b	2	-	2	-	2	-
	5b	3	-	1	2	3	-
	7b	3	-	2	1	2	1
Composite	1b	9	1	7	1	7	2
	3b	5	2	3	-	4	1
	5b	7	1	3	3	7	-
	7b	8	1	6	1	4	3

1 mph = 1.6 kph, 1 foot = .3 meters

(853 m) from the crossing. Generally, those trucks whose initial speeds were relatively high, i.e., greater than 50 mph (80 kph), appeared to be lightly laden (or empty) large trucks. When they were within a few hundred feet of the crossing, the speeds of these trucks were generally about the same as their initial speed. For these drivers, braking was normally limited to a "steadying" of the truck speed as they were about to pass over the crossing (a behavior also exhibited by numerous other vehicles, both during daytime and nighttime).

As can be seen from Table 20, daytime speed changes (deceleration) or acceleration) in the crossing approach rarely exceeded 1 - 2 mph (1.6 - 3.2 kph). Not shown in the table, but clearly the case from the raw data, is the fact that a speed change of 4 mph (6.4 kph) in the 2800-foot (853 m) approach zone was seldom observed.

Nighttime large truck traffic is minimal at this crossing. The few data samples that were taken over the four nighttime test periods are not shown. No change in speed selection behavior from day to night was seen.*

The operator of Radar #1 intermittently heard large trucks decelerating in advance of the AAWD location (during Tests 3, 5, 7) and observed several truck drivers turning their heads. Some indication of the impact of the AAWD (signs only) installation is obtained by examination of Table 20. During Test 1 prior to AAWD installation, only one of five (20%) large trucks in the lower 50 mph (80 kph) category showed a deceleration of 2 mph (3.2 kph) or more in Zone 1, while for Tests 3, 5, and 7, following installation of the AAWD, three of eight (38%) large trucks showed deceleration of 2 mph (3.2 kph) or more in the same zone. Due to small sample sizes, no level of statistical significance can be attached to these results.

Reporting of the speed responses of vehicles other than large trucks is divided into two parts:

1) Results observed in Zone 1, which ranges between 2800 feet (853 m) and 1600 feet (488 m) from the crossing, with the latter point immediately adjacent to the AAWD installation.

2) Speed behavior in Zone 2, which ranges from 1600 feet (488 m) to 600 feet (183 m) from the crossing.

Daytime Results (Zone 1)

Table 21 presents daytime speed changes for all vehicles except large trucks and other combinations estimated to be greater than 5 tons in gross weight. Approach Zone 1 does not differentiate between a and b tests

---

* Of interest, however, is the fact that of eight nighttime observations of large trucks, two were gasoline tank trucks (18 wheels), and both of them were radar clocked in excess of 50 mph (80 kph) over the crossing. There was no evidence that the crossing was EXEMPT from the mandatory stop required for these vehicles.

Table 21

Daylight Vehicle Speeds
Amador Central Railroad Crossing
(2800 - 1600 Feet From Crossing)

Initial Speed	Test No.	Sample Size	Frequency of Occurrence of Observed Speed Changes — ZONE 1: S_1: {2800 Feet}, S_2: {1600 Feet} — Acceleration $(S_1 - S_2) \leq -2$ mph	No Change $\lvert S_1 - S_2 \rvert \leq 1.0$ mph	Deceleration $(S_1 - S_2) \geq 2$ mph	Acceleration Range (mph)	Deceleration Range (mph)
55 mph and under	1ab	14	6	8	-	2-8	-
	3ab	9	4	5	-	3-9	-
	5ab	11	2	7	2	2-3	2-5
	7b	7	2	5	-	2-3	-
	7a	9	2	5	2	2	2
Over 55 mph	1ab	16	4	9	3	2-3	2-4
	3ab	11	1	5	5	2	2-4
	5ab	11	-	8	3	-	2-5
	7b	10	-	6	4	-	2-4
	7a	8	-	3	5	-	2-18
Composite	1ab	30	10	17	3	2-8	2-4
	3ab	20	5	10	5	2-9	2-4
	5ab	22	2	15	5	2-3	2-5
	7b	17	2	11	4	2-3	2-4
	7a	17	2	8	7	2	2-18

a: Denotes data with signals flashing.
b: Denotes data without signals flashing.
ab: Denotes both sets of data.
1.0 mph = 1.6 kph, 1.0 foot = .30 meter.

for Tests 1, 3, 5 since the crossing lights were not activated until the target vehicle was already through Zone 1, at 1000 feet (305 m) from the crossing. For Test 7, on the other hand, there were yellow signals mounted on the AAWD, and for Test 7_a these signals were activated when the target vehicle reached a point 2400 feet (732 m) from the crossing.

Examination of the data in Table 21 for vehicles whose initial speeds are in excess of 55 mph (89 kph) provides the most significant information. Pertinent points extracted from the tabled data are:

> In terms of relative frequency of acceleration, during Test 1, 4 of 16 (25%) exhibited acceleration behavior in Zone 1, as compared with only one vehicle in 40 (2.5%) during Tests 3, 5 and 7 (a and b). This difference is statistically significant ($p \leq .025$) indicating that the AAWD, with or without lights, was successful in bringing about a decrease in vehicle acceleration over Zone 1.
>
> The novelty effect of the sign installation is seen in comparing frequency of deceleration (versus no change or acceleration) for the over 55 mph (88.5 kph) vehicles in Tests 1 and 3, i.e., 3 decelerations vs. 13 no-change or accelerations (Test 1) compared to 5 decelerations vs. 6 no-change or accelerations (Test 3). This difference is statistically significant ($p \leq .06$) and is suggestive of the novelty effect. Furthermore, the novelty effect appears to decrease with Test 5, but increases again with Test 7_b (lights added but not activated).
>
> Test 7_a (lights activated) produced a 2 mph (3.2 kph) or greater deceleration in 5 of 8 target vehicles over the speed limit. The impact of the lights is better seen in the deceleration range column, which shows changes ranging from 2 to 18 mph (3.2 - 29 kph), versus a maximum change of 5 mph (8 kph) for all other tests in this speed category.

Daytime Results (Zone 2)

Zone 2 speed data covers vehicle passage from 1600 feet (488 m) in advance of the crossing to a point 600 feet (183 m) from the crossing (see Figure 55). The results of daytime deceleration analysis for Tests 1, 3, 5, and 7 are summarized in Table 22. Conclusions that may be drawn from this table are as follows:

> A comparison of Tests 1_a and 1_b indicates increased deceleration frequency with crossing signal activation (Test 1_a) for all speeds combined, with vehicle position at brakelight activation varying (in speed category averages) between 365 feet (111 m) to 200 feet (61 m) in advance of the crossing. (Subtracting the average distance traveled before brakelight activation (Table 22) from 1000 feet (305 m) will give the average distance in advance of the crossing where brakelights were displayed.)

Table 22

Daytime Vehicle Speeds
Amador Central Railroad Crossing
(1600-600 Feet From Crossing)

Speed At 1600 Ft. (S_2)	Test No.	Sample Size	Frequency of Occurrence of Observed Speed Change S_2 {1600 Ft.} - S_3 {600 Ft.}		Deceleration Range (mph)	Number Of Brakelights Observed	Average Distance Traveled Before Brakelight Activation (feet)	Vehicles Running Signals (Speeds > 40 mph)
			No Change $\lvert S_2-S_3\rvert \leq 2$ mph	Deceleration $(S_2 - S_3) > 2$ mph				
55 mph and Under	1b	5	3	2	3-4	N/A	N/A	N/A
	3b	3	2	1	8	N/A	N/A	N/A
	5b	8	8	-	-	N/A	N/A	N/A
	7b	8	7	1	4	N/A	N/A	N/A
	1a	8	4	4	3-5	1	800	3
	3a	3	3	-	-	2	650	1
	5a	3	3	-	-	3	700	-
	7a	14	7	7	4-7	10	495	2
Over 55 mph	1b	9	8	1	3	N/A	N/A	N/A
	3b	2	-	2	4-5	N/A	N/A	N/A
	5b	5	5	-	-	N/A	N/A	N/A
	7b	8	7	1	5	N/A	N/A	N/A
	1a	8	4	4	3-5	7	675	1
	3a	11	6	5	3-10	9	605	2
	5a	6	5	1	6	1	750	5
	7a	2	-	2	3	1	500	1
Composite	1b	14	11	3	3-4	N/A	N/A	N/A
	1a	16	8	8	3-5	8	650	4
	3b	5	2	3	4-8	N/A	N/A	N/A
	3a	14	9	5	3-10	11	610	3
	5b	13	13	-	-	N/A	N/A	N/A
	5a	9	8	1	6	4	713	5
	7b	16	14	2	4-5	N/A	N/A	N/A
	7a	16	7	9	4-7	11	495	3

a: Denotes data with signals flashing.
b: Denotes data without signals flashing.
ab: Denotes both sets of data.
N/A: Non Applicable.
1.0 mph = 1.6 kph, 1.0 foot = .30 meter.

A comparison of deceleration frequencies in Tests 3_a and 3_b shows decreased frequency of deceleration from Zone 2 when the railroad signals were activated. No significance is attached to deceleration frequency comparisons between Tests 1_a and 3_b nor is any meaning attached to the difference between their data on distance before brakelight onset, 650 feet (198 m) versus 610 feet (186 m), respectively. Likewise, the number of vehicles running the signals, 2 of 14 for Test 3_a, is not considered significantly different from the 4 of 16 who ran the signals during Test 1_a. It should be pointed out that a full stop at the activated crossing signals was a rarity in the daytime, with roughly three of every four vehicles failing to stop and driving over the crossing at a speed of 10 mph (16 kph) or greater.

The conduct of Test 5_a, which was separated from Tests 1 - 4 by a 4-week interval, quickly revealed that conditions had changed in the interim period. Of the first 9 vehicles for whom there was crossing signal activation, one came to a stop, 3 ran over the crossing at slow speeds and 5 ran the signals at high speeds. An inspection of the activated crossing signals from the approach roadway revealed that the crossing signals were so misaligned that the driver could see only one of the two heads flashing at distances greater than 300 feet (91 m). An initial inspection of the railroad signals prior to Tests 1 - 4 had revealed the alignment could be improved; however, there was no difficulty in discerning that a pair of heads were alternately flashing. No changes in signal alignment were made. However, a further signal misalignment apparently occurred between Tests 1 - 4 and Tests 5 - 8. As a consequence, the results of Test 5_a can be compared only with those of Test 7_a, which also was conducted during the second test period.

Speed data show that deceleration frequency increased in Zone 2 when both the AAWD and crossing signals were activated (Test 7_a), compared to Test 5_a which involved crossing signal activation only. The key point in the comparison is the average observed travel distance before brakelight illumination, i.e., 495 feet (151 m) for Test 7_a versus 733 feet (223 m) for Test 5_a. What these data reveal is that the activated AAWD was highly successful in alerting the driver to look for the crossing signals which had proven to be highly inconspicuous daytime targets in Test 5_a. It is interesting to note that despite this success, 3 of 16 target vehicles (Test 7_a) still ran the crossing at high speed. Two of the 3 drivers did not alter their speeds nor did they display brakelights. The third driver slowed somewhat from an initial speed of 62 mph (99.8 kph) but displayed no braking. Clearly, provision of safe stopping sight distance doesn't insure safe stopping behavior. The 15 incidents of "running" the crossing signals, plus numerous failures to stop at this crossing, cast considerable doubt upon the ability of railroad signals (without gates) to effect a high degree of driver compliance with the mandatory stop requirement, at least where high prevailing speeds are involved.

Nighttime Results (Zone 1)

Nighttime vehicle speed responses are shown in Table 23. What is not seen in the table, but appears in the raw data, is that the nighttime variance in speeds is much greater than that in the daytime.

Looking at acceleration versus deceleration frequencies in Table 23, it can be seen that:

1) The tendency to accelerate in the 1200-foot (366 m) stretch of roadway immediately preceding the AAWD location was greater than the tendency to decelerate. For example, a 3:1 ratio of accelerations to decelerations is seen in the composite Test 2 results.

2) Installation of the primary sign and message plate altered the the acceleration/deceleration ratio to 5:7 (composite results - Test 4). However, this ratio returned to 2:1 four weeks later (composite results - Test 6), when most of the novelty effects had presumably worn off. Tape recorder difficulties resulted in a loss of some data points for Test 8_b (AAWD not activated); however, the 3:1 ratio, based on 6 data points, is considered a fair appraisal of the time acceleration/deceleration ratio.

3) The 0:7 acceleration/deceleration ratio found with an activated AAWD in the composite results Test 8_a, together with the Zone 1 deceleration range of 2 - 17 mph (3.2 - 27.4 kph), is a significant but not unexpected change in speed selection approaching the AAWD location. Trial vehicular runs revealed that if a vehicle with low initial speed is allowed to coast, its speed will increase over this roadway section. Only a high initial speed with considerable engine and wind drag can result in a maximal vehicle deceleration of 4 mph (6.4 kph) over this downgrade section without brake application.

4) Nighttime activation of the AAWD (Test 8_a) produced deceleration in 7 of 11 (64%) approach vehicles over both speed categories, compared to 13 of 77 (17%) for all other tests. This difference is significant (at $p \leq .002$). Once again, the degree of maximum deceleration produced, 15 - 17 mph (24 - 27 kph), is much larger than for Tests 2 (no sign), 4 and 6 (AAWD without lights).

Additional statistical comparisons of test results were not attempted due to the fact that the raw speed data reveals a wide variation in speed behavior in the zone approaching the AAWD. It was, however, possible to conclude that:

A desirable speed change behavior occurred after initial installation of the primary sign and message plate,

This speed change behavior became less evident with time,

The amount of residual effect remaining (Test 6) is unknown, and

Table 23

Nighttime Vehicle Speeds
Amador Central Railroad Crossing
(2800 - 1600 Feet From Crossing)

Initial Speed	Test No.	Sample Size*	Frequency of Occurrence of Observed Speed Changes ZONE 1: S_1: {2800 Feet}, S_2: {1600 Feet} Acceleration $(S_1 - S_2) \leq 2$ mph	No Change $\lvert S_1 - S_2 \rvert \leq 1.0$ mph	Deceleration $(S_1 - S_2) \geq 2$ mph	Acceleration Range (mph)	Deceleration Range (mph)
55 mph and under	2ab	11	4	6	1	2-6	2
	4ab	20	2	12	6	2-3	2-5
	6ab	17	4	13	-	2-5	-
	8b	4	3	1	-	2-8	-
	8a	4	-	2	2	-	12-17
Over 55 mph	2ab	14	5	7	2	2-5	3
	4ab	15	3	11	1	2	2
	6ab	19	6	8	5	2-5	2-8
	8b	2	-	1	1	-	4
	8a	7	-	2	5	-	2-15
Composite	2ab	25	9	13	3	2-6	2-3
	4ab	35	5	23	7	2-3	2-5
	6ab	36	10	21	5	2-5	2-8
	8b	6	3	2	1	2-8	4
	8a	11	-	4	7	-	2-17

a: Denotes data with signals flashing.
b: Denotes data without signals flashing.
ab: Denotes both sets of data
1.0 mph = 1.6 kph, 1.0 foot = .30 meter.

The location of the AAWD, centered in the driver view of the roadway ahead, undoubtedly contributed to the overall impact of the device.

Nighttime Results (Zone 2)

The previously-described problems with signal alignment and lack of daytime visibility of the railroad signals did not present similar difficulties at night, due to high-contrast background conditions. The approaching driver was able to see the alternately flashing crossing signals over the entire 1000-foot (305 m) roadway section immediately in advance of the down-grade approach to the crossing. However, proper alignment would have made the signals far brighter than they were.

The nighttime vehicle speed response data in Zone 2 are shown in Table 24. The difference between these results and the daytime results in the same roadway section (Table 22) lies in the approach vehicle driver's ability to perceive the crossing signals at a far greater distance at night. Table 24 reveals that:

For vehicles moving under the 55 mph (88.5 kph) speed limit when they passed the AAWD, there were no cases of appreciable deceleration over the next 1000-foot (305 m) section of roadway when the crossing signals were not activated (Tests 2_b, 4_b, 6_b, 8_b). There was, however, some deceleration observed in vehicles which were over the speed limit at the AAWD location under the same conditions.

Activation of the crossing signals resulted in decelerations for all but one target vehicle in the 1000-foot (305 m) roadway section between the AAWD location and a point 600 feet (183 m) in advance of the crossing (Zone 2).

Comparison of the data on deceleration range and travel distance before brakelight illumination for Tests 2_a, 4_a, and 6_a reveals differences that are believed to fall within the range of estimational error of the field observers. The only difference truly discernible by the field test personnel, and reflected in the data, concerned Test 8_a when the AAWD was activated. During the conduct of Test 8_a, noticeably quicker driver responses (brake application) occurred, and this is reflected in the average vehicle travel distance before brakelight illumination. There was one vehicle already slowing (brakes applied) when the crossing signals were activated.

8.4.2 Other Results

Results of the tests at the first two field sites together with the first week of tests at the Amador Central Crossing left the researchers convinced that installation of a new advance warning primary sign and supplemental message would produce a novelty effect which could be measured by speed reduction in a zone around the sign itself. Furthermore, this speed reduction would apply to

Table 24

Nighttime Vehicle Speeds
Amador Central Railroad Crossing
(1600-600 Feet From Crossing)

Speed At 1600 Feet (S_2)	Test No.	Sample Size	Frequency of Occurrence of Observed Speed Change S_2 {1600 Feet} - S_3 {600 Feet}		Deceleration Range (mph)	Travel Distance Before Brakelight Activation (feet)	
			No Change $\|S_2-S_3\| \leq 2$ mph	Deceleration $S_2-S_3 > 2$ mph		Range	Average
55 mph and Under	2b	4	4	-	-	N/A	N/A
	4b	12	12	-	-	N/A	N/A
	6b	7	7	-	-	N/A	N/A
	8b	3	3	-	-	N/A	N/A
	2a	4	1	3	10-17	150-200	175
	4a	2	-	2	5-11	200	200
	6a	6	-	6	3-12	100-200	150
	8a	5	-	5	4-17	0-100	40
Over 55 mph	2b	9	5	4	2-4	N/A	N/A
	4b	9	8	1	4	M/A	N/A
	6b	15	12	3	3-4	N/A	N/A
	8b	3	3	-	-	N/A	N/A
	2a	5	-	5	2-16	150-300	210
	4a	6	-	6	6-11	150-200	175
	6a	5	-	5	5-15	100-250	175
	8a	5	-	5	3-30	0-200	100
Composite	2b	13	9	4	2-4	N/A	N/A
	4b	21	20	1	4	N/A	N/A
	6B	22	19	3	3-4	N/A	N/A
	8b	6	6	-	-	N/A	N/A
	2a	10	1	9	2-17	150-300	195
	4a	8	-	8	5-11	150-200	180
	6a	11	-	11	3-15	100-250	160
	8a	10	-	10	3-30	0-200	70

a: Denotes data with signals flashing.
b: Denotes data without signals flashing.
ab: Denotes both sets of data.
N/A: Non Applicable.
1.0 mph = 1.6 kph, 1.0 foot = .30 meter.

only a portion of the traffic; the remainder would be unaffected in speed by the sign. This does not mean the advance signing did not have some positive effect on the latter drivers, but only that the effect was not measurable through a speed change. It was further recognized that the proportion of drivers exhibiting a speed reduction in the zone around the AAWD would undoubtedly decrease as time passed and whatever residual effect remained would more likely be due to sign (or device) credibility than to a continuing novelty effect of the device itself. It was further felt that the particular location of the device at the Amador Central Crossing, directly in the driver's view, could be superior to the standard, right-side-of-the-road location (along a tangent roadway section) used in the first two field sites.

Following completion of the first week's tests (Tests 1 - 4) at the Amador Central Crossing, the researchers elected to take a closer look at speed behavior concurrently with driver looking behavior in a 600-foot (183 m) roadway section immediately preceding the AAWD location. Based on previously-observed data, and in an effort to keep subjectivity out of the process of recording looking behavior, a head movement was defined to be an obvious turn of the driver's head (to the left) as he passed the AAWD. The speeds to be used for analysis would be taken at 2200 feet (671 m) in advance of the crossing, and at 1600 feet (488 m), the point of vehicle passage of the AAWD. The AAWD containing Primary Sign C had been in position for two days at the end of the first week's tests. In an effort to maximize the opportunity to observe the novelty effect, Sign C was replaced with Primary Sign B. Thus, the AAWD sign configuration at the Amador Central Crossing was exactly that tested at the Santa Fe Crossing (see Figure 51), but no lights were displayed and the location was on the left side of the road. Driver behavior, in terms of speed and looking, is shown in Table 25. Classifying both acceleration and deceleration as a 2 mph (3.2 kph) change over the 600 foot (183 m) roadway section, the following comparisons can be made between Tables 21 and 25.

> With Primary Sign B installed the acceleration/deceleration ratio (1:3) for vehicles (excluding large trucks) traveling under 55 mph (89 kph) is less than the same ratio obtained in Test 1 (pre-existing) and in Test 3 (immediately following installation of Primary Sign C).
>
> With Primary Sign B in place, the same acceleration/deceleration ratio for vehicles (large trucks excluded) exceeding the speed limit is far smaller than it was under pre-existing conditions (Test 1); a comparison with Sign C (Test 3) is inconclusive, due to small sample sizes.

Immediately following the foregoing tests, primary Sign C was reinstalled on the AAWD post and remained there for the four week interval preceding conduct of Tests 5 - 8.

8.4.3 Amador Central Crossing Conclusions

The conclusions drawn from conduct of tests at the Amador Central Railroad crossing are listed below:

Table 25

Driver Head Movements and Deceleration

(PRIMARY SIGN B and WATCH FOR TRAINS Message)*

Initial Speed	Vehicle Type	Sample Size	Frequency of Observed Zonal** Speed Changes			Average Acceleration (mph)	Average Deceleration (mph)	Observed Number of Head Movements
			Acceleration (≥ 2 mph)	No Change	Deceleration (≥ 2 mph)			
55 mph or Less	Lt	5	1	3	1	3.0	5.0	1
	AO	15	2	7	6	3.0	4.0	4
Over 55 mph	Lt	2	-	1	1	-	2.0	-
	AO	5	-	2	3	-	9.0	-

* Temporarily installed at the Amador Central Crossing

** Speed Measurement Zone: 2200 feet (671 m) to 1600 feet (488 m)

Lt: Large trucks - 18 wheels or more

AO: All other vehicles

1.0 mph = 1.6 kph

1) The AAWD was very effective in slowing driver speeds and preparing them for activation of the crossing signals. The conclusion is supported by observed speed reductions in advance of the AAWD and a quicker driver response as evidenced by roadway location of brakelight activations following activation of the crossing signals.

2) Delayed daytime perception of flashing crossing signals was due in part to misaligned crossing signal heads. How much this misalignment contributed to the driver running through flashing signals is unknown. It is envisioned that lack of credibility and enforcement of the mandatory stop rule for crossing signals <u>without</u> crossing gates are contributory reasons for the high speed running of the crossing signals. The frequency of this behavior was much higher during daylight hours than during hours of darkness.

3) There was an indication that the AAWD without the 8-inch yellow signals was registering in the mind of drivers, i.e., increased speed reduction frequencies. However, the speed and braking data do not contain enough resolution to detect whether or not the sign components (Tests 3 - 6) were successful in preparing the driver for crossing signal activation.

4) As with other sites, the large change in driver behavior was produced when the AAWD was activated. The ability of a pair of activated yellow flashing signals coupled with sign messages to produce desirable driver responses was clearly demonstrated at the Amador Central Railroad Crossing site.

8.5 Field Test Conclusions

General conclusions drawn from the field tests are as follows:

The simple pair of activated, alternately-flashing yellow lights are adequate to gain the driver's attention and alert him to an impending roadway situation ahead. That is, they produced deceleration in themselves and shortened the driver's perception and reaction time to crossing signal activation. Their most positive benefit observed is during daylight hours, when visible but inconspicuous railroad crossing warning signals are located away from the driver's line of sight and may not be perceived in sufficient time to permit safe stopping. In this situation, the flashing lights appear to prompt the driver to "look around".

Field site differences as well as the loss of radar data at the Santa Fe crossing site preclude direct comparison of results of the three field tests. In terms of field MOE's all three primary signs can be concluded to "do-the-job". The unanswered questions from field test results were: "What type of message does the driver desire in addition to the activated yellow signals?" and "What credibility will he attach to that message?" Driver interviews during the field tests would have provided additional insight to the foregoing questions; however, it is not clear that such data would add significantly to the expressed desires of the laboratory test subjects.

Research is needed to establish realistic braking deceleration rates for large trucks operating at highway speeds. Classical braking distance estimates are discussed in Section 9. Based upon observed driver behavior of large trucks, it is not clear that classically derived wet pavement braking distances and their resulting deceleration rate requirements are unacceptably high.

9.0 GUIDELINES

In general, the types of crossings which warrant installation of an AAWD can be characterized as those whose signals, or signals and gates, do not provide "safe stopping sight distance" on one or more approaches to the crossing. There is no reason to install AAWD's on all approaches to a crossing if, for example, only one approach fails to provide safe stopping sight distance.

9.1 Safe Stopping Sight Distance

The term "safe stopping sight distance" refers to the driver's ability to perceive a hazard in his path in time and to come to a complete stop before reaching that hazard. Safe stopping sight distance has been classically defined as the sum of two distances;

1) Perception and Reaction Distance: Perception and Reaction Time multiplied by approach speed in feet per second, and,

2) Braking Distance: a function of approach speed, the grade of the approach roadway and the coefficient of the friction of the pavement.

9.1.1 Braking Distance

Braking distance is derived from the formula

$$B.D. = \frac{V^2}{30(f+g)},$$

where,
B.D.= braking distance, in feet,
V = Vehicle speed in mph at onset of braking,
f = coefficient of friction and
g = percent grade divided by 100 (+ for uphill).

For highway design and traffic engineering purposes, the coefficients of friction used are those for wet pavement. The values of f used are taken from Glennon (35), and they are more conservative (i.e., lower) than those set forth by AASHO (36).

9.1.2 Perception and Reaction Time

The key to safe stopping sight distance (SSSD) is the driver's perception and reaction time (PRT). A PRT of 2.5 seconds is used to calculate the SSSD. The 2.5 second figure is commonly used for highway design purposes; it is considered liberal, and should be adequate for all but the very slowest-reacting drivers.

Figure 61 depicts safe stopping sight distance as a function of crossing approach speed, assuming a 2.5 second PRT, zero grade and wet pavement.

9.1.3 Applicability of the SSSD Concept to Activated Advance Warning

Two key questions must be addressed before conclusions can be drawn regarding the applicability of the SSSD concept to activated advance warning crossings:

1) Is the braking distance formula reasonably accurate for the type of traffic operating on the roadway?

2) Under what conditions is the 2.5 second PRT valid?

Complete resolution of these questions is complex, and falls outside the scope of this project; however, the following sections describe how the researchers addressed these issues.

Braking Distance

Due to a lack of sufficient data, it is not clear whether or not the foregoing wet pavement-derived braking distances are within tolerable deceleration limits for large,heavily-laden trucks. Secondly, there are some economic overtones in considering whether or not a large truck driver will elect to stop his vehicle if the alternative to not stopping carries little risk, i.e.,deceleration produces brake wear, lost time and excess gasoline consumption in accelerating to highway speed. Giving due consideration to the foregoing factors, it would appear that the concept of "tolerable deceleration" rather than braking distance would be a better framework to describe a vehicle's stopping maneuver, particularly a large truck.

Acceptable deceleration is a topic discussed by Bissell and Warren (37) in regard to determining the length of the yellow interval of a traffic signal. They reference the work of Olson and Rothery (38) who found that drivers were virtually certain to stop at a traffic signal if their required deceleration rate was less than 8 feet/sec^2 (2.4m/sec^2) and virtually certain to continue if the rate was greater than 12 feet/sec^2 (3.6m/sec^2). How applicable these results are to large high speed trucks, on either wet or dry pavements, is unknown.

It can be shown that the braking distance formula with f=.22, requires an average deceleration of 8.7 feet/sec^2 (2.65m/sec^2) at 65mph (105kph) and this deceleration steadily increases to a value of 11.3 feet/sec^2 (3.43m/sec^2) at 30mph (48kph) with f=.30. There is strong circumstantial evidence that these deceleration ranges prescribed by the braking distance formula are excessively high for large trucks. Such evidence includes:

1) There appears to be a total lack of braking distance data or tolerable deceleration rates for large trucks at speeds greater than 20mph (32kph).

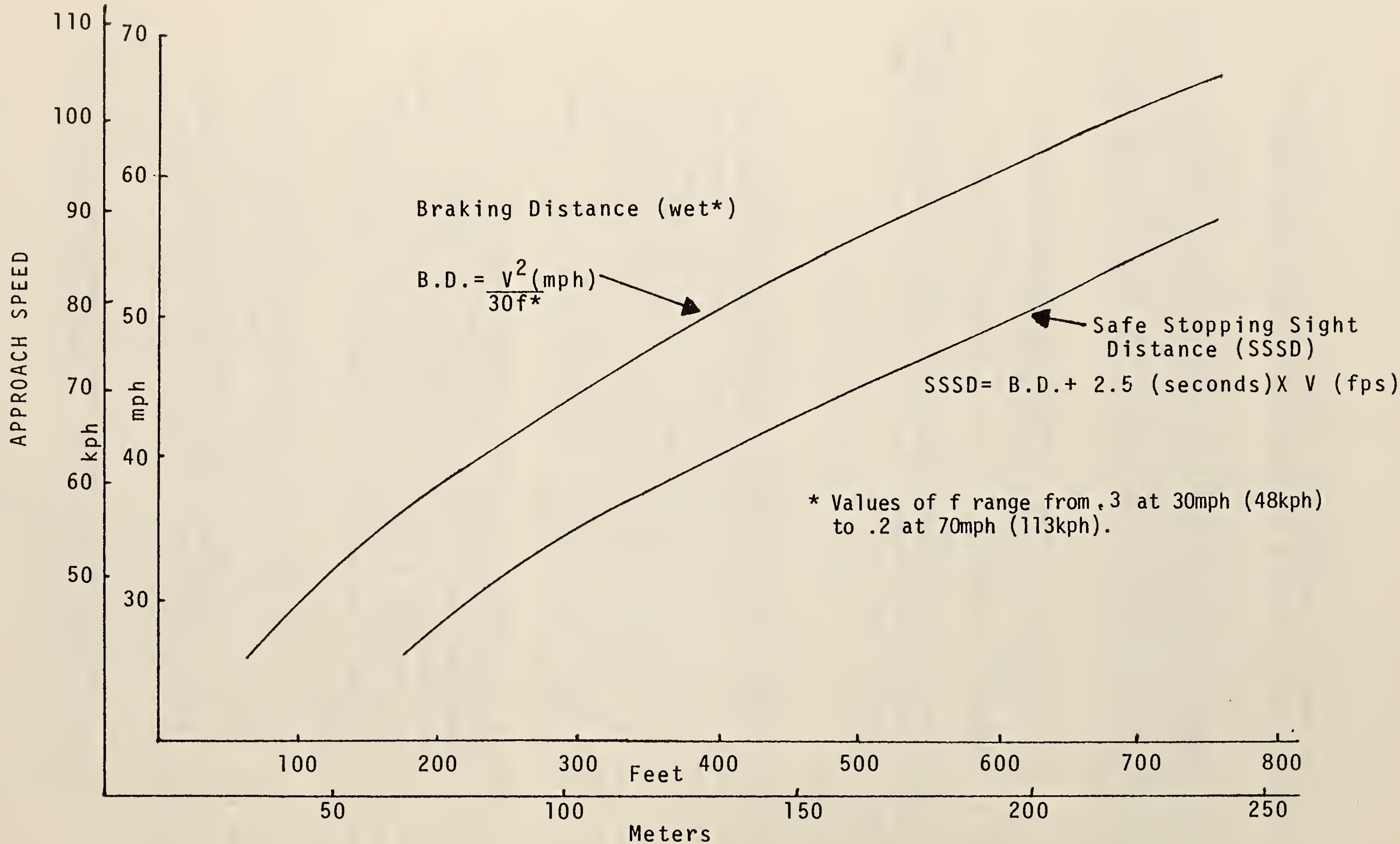

Figure 61

Safe Stopping Sight Distance
(Zero Grade, Wet Pavement)

2) In conducting the field tests there were numerous unexplained observations of excessively long skid marks from dual wheel axles. Observed skid marks of 750 feet (229m) would indicate that the vehicle producing this mark would have been traveling roughly 106mph (171kph) at the onset of tire skidding -- if the vehicle was capable of braking within the distances prescribed by the braking distance formula. Although this speed is not beyond the realm of possibility, the 131mph (211kph) speed necessary to produce an observed 1150 foot (351m) skid mark is, in all likelihood, an impossibility.

3) There was general consensus expressed by a number of highway and law enforcement personnel that braking distances for large trucks are typically much greater than what one would expect for smaller vehicles, particularly on down grades.

Giving due consideration to the foregoing, the research staff elected to use lesser deceleration rates than those prescribed by the braking distance formula. In a somewhat arbitrary decision, the research staff selected the deceleration rate of 8 feet/sec^2 quoted by Olson and Rothery (38), and decreased it by roughly 35% for high speed rural road traffic containing a significant amount of large truck traffic. The rationale for the resulting deceleration rate of 5 feet/sec^2 (1.52m/sec^2) was two-fold:

1) The quoted 8 feet/sec^2 (2.4m/sec^2) is likely too high for high speed traffic and wet pavement conditions, and

2) The economic costs, fuel, tire and brake wear, associated with stopping and reestablishing highway speeds for larger trucks are likely such that drivers will elect not to stop, unless the required deceleration rate is low or the risk of not stopping is high.

The fact that lack of adequate data required the researchers to somewhat arbitrarily establish a deceleration distance points out the need for additional research in this area. Particular emphasis should be placed upon the increased costs of vehicle maintenance resulting from heavy braking requirements.

Perception and Reaction Time

Perception and reaction to flashing railroad signals is generally considered a daytime visibility problem, since at night, the signals are usually far more visible due to a higher background contrast and (generally) less visual "clutter" providing competition. Located in urban areas where there is an excessive amount of competing lights, PRT becomes a conspicuity issue related to the ability of visible, flashing railroad signals to gain the driver's attention.

9.2 Guidelines for Establishing Signal Perception Requirements

This section discusses the roles played by roadside clutter, driver visual field and crossing signal alignment in determining whether or not the approaching driver can be expected to perceive and react to flashing railroad signals in time to allow safe stopping distance.

9.2.1 Visual Clutter

If one considers a 55 mph (88.5kph) approach speed, the wet pavement braking distance is roughly 440 feet (137m). At this speed a 2.5 second perception and reaction time adds roughly 200 feet (61m) to this braking distance. Therefore the safe stopping sight distance is 660 feet (201m) in advance of the stop bar. If the previously described 5 feet/sec^2 (1.5m/sec^2) deceleration rate were used, rather than the traditionally derived braking distance, then the SSSD would be roughly 850 feet (259m). In either case, an approaching vehicle driver should have a relatively unobstructed, clutter-free view of the crossing signals, and this unobstructed view should continue throughout the entire 200 foot (67m) perception and reaction zone. Two examples of roadside "clutter" are shown in Figures 62 and 63. The reverse curve signs in both figures are vitally important warning signs; however, they are clutter relative to the driver's task of perceiving the flashing crossing signals that are centrally located in each reverse curve. The signs compete with the crossing signals for the driver's attention, thereby reducing the likelihood of the signals being perceived at sufficient distance. In addition, the telephone and power poles in Figures 62 and 63 add considerably to the visual clutter on the right side of the roadway, and constitute a type of barrier that makes it difficult to see the flashing red signals at a distance, i.e., against low-contrast daytime backgrounds.

In Figures 64 and 65, which are closer views of the reverse curve and crossing in Figure 63, one sees the persistent impact of the clutter caused by poles along the side of the road. The driver has been well warned of the reverse curve, and if he has received this message, it is reasonable to assume that his primary focus of attention will be on negotiating the curve, seen between the poles, rather than on looking into and beyond the curve for warnings or other visual cues having nothing to do with the curve itself. The prevailing speed through this reverse curve has been measured as higher than the posted advisory of 35 mph (56kph). Based on this prevailing speed, the beginning of the critical perception and reaction zone occurs slightly in advance of the reverse curve sign seen in Figure 64, and proceeds roughly to the position of the W10-1 seen in Figure 65. The positioning of the W10-1 at this site is poor; it should be located in advance of the perception and reaction zone, rather than being a source of clutter in the zone itself. Figure 65 shows the nearside crossing signals blocked from the driver's view by a pole. Upstream of the position represented by Figure 65, it is the W10-1 itself which obstructs driver view of the nearside crossing signals. Viewed at a distance of 500 feet (152m), the nearside signals are roughly 7-8° to the right of the driver's line of sight down the roadway ahead, and about 5° to the right when viewed at about 700 feet (213m) from the crossing. Were the existing signing moved farther in advance of the crossing and telephone poles removed, this site would have only a marginal need for AAWD installation, i.e., there would be little cause for concern as to whether or not a well-aligned set of flashing signals would capture the driver's attention in the critical perception and reaction zone.

Figure 62
Roadside Clutter
(Location 1)

Figure 63

Roadside Clutter
(Location 2)

Figure 64

Roadside Clutter
(Closer View)

Figure 65

Roadside Clutter
(Close Up View)

Another example of roadside pole clutter and a misplaced W10-1 (poorly seen due to sun angle) is shown in Figure 66. The railroad signals are seen here against a dark background (trees) and will be more easily perceived than those in the previous examples.

A final example is shown in Figure 67 where, despite roadside-mounted poles, a reverse curve and a railroad crossing, the near-side crossing signals lie close to the driver's line of sight. As a consequence, the driver is provided with safe stopping sight distance (assuming glare does not interfere with vision).

9.2.2 Driver Cone of Vision

The human eye is most sensitive to detail in the central portion of the visual field. In the normally-sighted individual, the best visual acuity is achieved for objects lying on or very close to the fixation axis, or "line of sight". It is possible to describe a "cone of clear vision" for a driver, and to use this concept as a guideline for placement of traffic control devices. The earliest use of this concept in relation to traffic safety was by Mitchell and Forbes (39), who defined the cone of clearest vision as being 5^{o} in extent (2.5^{o} to all sides of the line of sight). They further stated that visual acuity declines as we move outside this 5^{o} cone, until a 10^{o} cone is reached (5^{o} to all sides of the line of sight), at which point there is a sharp break in the acuity curve, with the images becoming noticeably fuzzier. They defined this 10^{o} cone as one of "fairly clear vision" and suggested that all signs be placed (and be of such size and design) that they are detectable and legible when lying within this cone.

Since the Mitchell and Forbes paper was published, there have been suggestions that a 15^{o} cone be used as a design limit; however, the 10^{o} cone would appear to be more in line with human visual capabilities and, thus, a more appropriate design value. This criterion requires, then, that the crossing signals fall within 5 degrees of an approaching driver's line of sight when he is at the safe stopping sight distance from the crossing. If this criterion cannot be met for a given crossing, then an AAWD installation may be warranted.

9.2.3 Railroad Signal Brightness

In addition to lying within the driver's cone of vision, the railroad signal must provide sufficient daytime brightness contrast to be detected. This is a problem for the very narrow beam width of the standard "30-15" railroad signal since a vertical deviation of 1^{o} from the beam axis may result in an 80% loss in photometric brightness while 90% of the photometric brightness is lost with a 1.5-2.0^{o} deviation (over or under) the horizontal beam axis. The decrease in signal brightness with horizontal deviation (right or left) from the vertical beam axis is much less, due to the elliptical nature of the beam patterns. Because of this tightly-focused beam, the aim is critical. To meet the safe stopping sight distance requirement, the signal alignment should be such that the central portion of the signal beam (roughly $\pm 1^{o}$ vertical and 5-7.5^{o} horizontal) impinges on the driver's eye as he traverses the PRT zone.

Figure 66

Pole Clutter
(With dark background framed signals)

Figure 67
Pole Clutter
(With minimal perceptual problems)

9.3 Establishing the Need for an AAWD Installation

To determine whether an AAWD installation is needed at a given site, an on-site analysis must be made to ascertain if safe stopping sight distance is currently provided by the crossing signals. This analysis can be carried out in the following manner:

1) Specify the approach speed and the corresponding conditions, e.g., 85th percentile speed and wet pavement.

2) Establish a realistic deceleration- braking distance. Use deceleration rates consistent with the roadway traffic composition.

3) Determine the length of and locate the 2.5 second perception and reaction zone on the crossing approach.

4) Determine if the driver will perceive the signals as he enters and proceeds throughout the perception and reaction zone. The following suggestions will aid in making this determination:

    a) Determine if the flashing signals are visible -- when looking at them directly -- throughout the zone.

    b) Check the railroad signal alignment.

    c) Triangulate the railroad signal alignment, the driver roadway view and the direct driver view of the railroad signals. Where is the driver in the railroad signal beam when traversing the perception and reaction zone?

    d) Determine where the signals are located in the driver's cone of vision as he proceeds through the perception and reaction zone.

    e) Analyze the roadside clutter in the perception and reaction zone. Photographs are the best method to evaluate clutter.

If it is possible for the driver to perceive the signals throughout the perception and reaction zone (with signal re-aiming, if necessary), then an AAWD is probably not needed.

9.4 Typical Railroad Crossing Types Warranting AAWD's

The types of crossings that generally provide insufficient safe stopping sight distance and, hence, can benefit most from installation of AAWD's, are:

1) Crossings with physical sight distance limiting constraints, vertical and/or horizontal;

2) Crossing approach roadways of such geometry that activated, crossing-located signals do not provide sufficient signal

brightness and/or lie too far away from the driver's line of sight when he is traversing the perception and reaction zone;

3) Crossings which require extended braking distances (e.g., due to downgrades), which in turn extend the beginning of the perception and reaction zone to such a distance that the crossing now falls under 1 or 2, above; and

4) Crossings which, due to intermittent (but regular) reduced visibility conditions fall into category 2, above. These are highly subject to fog, blowing dust, etc.

In an effort to discourage over-usage of what can be an extremely effective device, the researchers have specifically excluded:

1) The isolated crossing where the driver is not expecting to encounter an activated device which will require his stopping ahead. It is the position of the researchers that there are existing guidelines within the MUTCD for dealing with this situation, i.e., the continuously-active hazard warning beacon. A hazard warning beacon could be located at the crossing and extinguished with the railroad signal activation and/or located with the W10-1 in advance of the crossing and not be extinguished.

2) Other special situations in which careful analysis of the crossing, its approach roadway and the composition of the traffic stream will suggest the basis of the problem and its solution does not involve use of an AAWD. For example, a crossing experiencing excessive gate breakage may, in fact, need an AAWD, or the problem may be traceable to large trucks, for whom the crossing signals come on too late, i.e., there is a dilemma zone in which trucks can neither stop nor avoid lowering railroad gates. In the latter case the preferable solution would be to delay initiation of the downward gate movement.

9.5 AAWD Installation Guidelines

This section contains recommendations for installation of AAWD's.

9.5.1 Placement in Advance of Crossing

The safe stopping sight distance is used to establish the need for an AAWD and sets the minimum distance for placement of the AAWD in advance of the crossing. Having established this minimum distance, the next task is to maximize the distance at which approaching drivers can view the device. In accomplishing this, it is important to remember that if the safe stopping sight distance location is on a tangent roadway section (see Figure 50) it makes little sense to move the AAWD further upstream. If the safe stopping sight distance is located in a curving roadway section, it is recommended that the device be located further in advance of the crossing to maximize its driver viewing distance and that it be located to optimize the driver viewing angle (see next section).

9.5.2 Roadway Location

Standard right-shoulder mounting is recommended for devices on tangent roadway sections, as in Figure 50, or when the roadway curves to the left. For installation on a roadway that curves to the right, it is possible to maximize sight distance for the AAWD by placing it on the left side of the roadway, in the bend or knee of the curve as seen from the tangent roadway section (Figure 60). This recommended left-shoulder mounting is not in keeping with traditional right side of road positioning. Centering the device within the driver's cone of vision is considered more important than traditional right-shoulder mounting. However, a redundant installation consisting of both left and right side of road installations will satisfy both optimal location (centered in the driver's cone of vision) and traditional right side of road positioning.

No particular emphasis is placed on cantilevered, over-the-roadway mounting, since the increased costs of such an installation are often not warranted by local conditions. A dual installation, i.e., mounting AAWD's on both sides of the roadway, is often cheaper than over-the-roadway mounting, with a gain in driver conspicuity resulting from the redundancy. Prior research (5) has indicated that under daytime fog conditions, flashing lights mounted on the right shoulder were more conspicuous than those mounted over the roadway.

9.6 AAWD Operation Guidelines

As previously indicated, standard railroad crossing signals suffer from two operational deficiencies when compared to a standard traffic signal. The first is the lack of any positive indication that an inactivated signal is functional and that the right of way at the crossing belongs to vehicular traffic until the railroad signal is activated. The second deficiency is that activation of railroad signals presents the driver with a low-probability event devoid of any pre-warning or clearance interval such as that provided by the yellow display of a traffic signal.

9.6.1 AAWD Activation

The operation of an AAWD, where warranted, can serve to offset the lack of a clearance interval display by the crossing signals. This can be accomplished by delaying activation of the crossing signals until after activation of the AAWD by a time interval which is equal to the approach vehicle passage time between the AAWD location and the crossing location. This concept was put forth by Wilde, et al. (3), and would allow those drivers located between the AAWD and the crossing to clear the crossing before the unexpected activation of the crossing signals occurred. For vehicles approaching the AAWD at a distance greater than the SSSD, activation of the device will prepare them for an otherwise unexpected, subsequent event--activation of the crossing signals. Constraints like a minimum signal display time at the crossing, the type of train detection circuitry in use and the range of train approach speeds may make it necessary to modify the train detection circuitry at a specific crossing to assure that a pre-warning period can be provided safely. A side benefit of clearing vehicles caught between the AAWD and the crossing when the train arrives, is an improvement in the method of removing vehicular right-of-way at the crossing. This improvement will decrease fuel consumption by clearly separating approach traffic into two groups, i.e., those drivers downstream of the AAWD who receive no stopping indication and those upstream of the AAWD who are prewarned of their upcoming downstream stopping maneuver.

From field test observations it would appear that large truck driver behavior characteristics coupled with tolerable braking deceleration rates of their vehicles will dictate the distance in advance of the crossing for AAWD location, and the delay time between AAWD activation and activation of the crossing signals.

A delay time example can be described using data from one of the field sites. As previously described (Section 2), AAWD placement was 1000 feet (305m) in advance of the Santa Fe crossing. Although the researchers observed a wide variation in large truck speeds approaching the crossing, the maximum travel time for these vehicles between the AAWD and the crossing was 17.5 seconds. This travel time amounts to an average travel speed of 39mph (63 kph) over the 1000 feet (305m) zone. Furthermore, based on a sample of 25 large trucks, their mean travel time between the AAWD and the crossing was 13.5 seconds with a standard deviation of 1.5 seconds. Observed travel times of other vehicles revealed a minimum travel time of 9.8 seconds for the same 1000-foot (305m) zone. The foregoing data are important to specification of the fixed delay time. If the delay time is long (to clear slow moving traffic) then the high speed driver just glimpsing AAWD activation as he passes the device will be too far past the crossing when the crossing signals activate. From the foregoing data, a 13-14 second delay interval would seem optimum for an AAWD placed 1000 feet (305m) in advance of the Santa Fe crossing. A high speed vehicle seeing activation of the AAWD would be less than 300 feet (91m) past the crossing when the crossing signals activate. A slow speed truck, just failing to see activation of the AAWD, would be within 4 seconds of passing over the crossing when the crossing signals activate. Since it takes 6.5 seconds from the time the signals activate to initiation of gate arm downward movement at the Santa Fe site, a slow speed truck will easily clear the crossing gates.

9.6.2 AAWD Deactivation

One of the more critical decisions involves deactivation of the AAWD. A potential rear-end accident situation is set up by stopped vehicles at the crossing. Continued activation of the AAWD during the time a train is passing will alert oncoming vehicles. The problem of clearing vehicle traffic following the train's passage cannot be treated in general but must be dealt with on a individual site basis. Few, if any, situations can be envisioned in which the AAWD would be deactivated before the crossing signals. A specific site may require holding the AAWD activated beyond deactivation time of the crossing signals. The foregoing can be accomplished by techniques ranging from use of a simple delay timer to a more sophisticated treatment employing vehicle presence detectors located in the roadway zone directly upstream of the stop bar.

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APPENDIX A

This appendix contains a detailed presentation and interpretation of driver speed response data taken at two of the three field sites discussed in Section 8.0 of this report.

A.1 Southern Pacific Crossing

Tables A-1 through A-8 present the summary speed data for Tests 1-4 of the first test period. Two tables are shown on each page: the upper table presents data on driver response to activated signals; the lower table gives driver speeds in the same radar coverage zones, when railroad signals are not activated. Total speed change over a 1650-foot (503m) section of the approach roadway is also given.

Refinement of the method of recording speed data resulted in partitioning the long zone into three sequential zones for the second test period. Tables A-9 through A-22 depict the results of the second test period (Tests 5-8, excluding Test 7a). Tables are depicted two to a page, where the upper table partitions the long zone deceleration into 2 or 3 additive speed change components. Tables A-12, A-16 and A-22 representing Tests 5b, 6b and 8b, give additional data on speed change over a fourth zone -- the last 350 feet (107m) before the crossing.

Comparing Tests 5a with 7a and 6a with 8a, the speed change impact of AAWD activation can be seen both in Zones 1 and 2. Furthermore, AAWD activation, followed by crossing signal activation, produces additional deceleration (faster perception and reaction to the crossing signals) in Zone 3. Using the composite speed, passenger car unit (PCU) classification and average deceleration per zone, speed change for Zones 1 and 2 are 3 to 4 times that seen in these zones without AAWD activations while the speed change range of the zone reveals wide variation in the absolute amount of deceleration observed between individual drivers.

A.2 Santa Fe Crossing

Radar speed readings for the first week of testing at the Santa Fe crossing are shown in Tables A-23 through A-29 (Tests 1, 2 and 4). As was explained earlier all data for Test 3a were lost. Only two data points were taken on Test 3b before the radar was discovered by a passing truck driver.

The technique of zone passage time clocking to extract an average zone speed was used during the second week of tests. As discussed in the text, the change in speed calculated from zone passage times is likely to be below what radar measurements would have given by a factor ranging from 3:1 to 5:1 or more. Due to this variation, only two Tests (5a and 7a) were put in the form of vehicle speed based on zone travel time, and included herein. The two tests are shown in Tables A-29 and A-30.

TABLE A-1
Southern Pacific Railroad Crossing

(Test 1a)

Initial Speed * Category	Vehicle Type **	Sample Size	Initial Speed *		Speed Change * Zones 1-3 +	
			Range	Average	Range	Average
0 - 45	PCU AO Lt	4 1 1	40-44 39 40	42 39 38	2-8 3 2	5.4 3 2
46 - 55	PCU	7	48-55	51.1	2-19	7.7
Over 55	PCU	5	56-75	61	5-29	11.8
Composite	PCU	16	40-75	50.3	2-29	8.44

Test 1a: Daytime, Preexisting Conditions, Crossing Signals Activated

TABLE A-2
Southern Pacific Railroad Crossing
(Test 1b)

Initial Speed* Category	Vehicle Type **	Sample Size	Initial Speed *		Speed Change * Zones 1-3+	
			Range	Average	Range	Average
0 - 45	AO PCU	1 2	41 41-44	41 42.5	3 3-6	3 4.5
46 - 55	AO PCU	2 13	52-53 46-55	52.5 50.2	5-14 1-11	9.5 5.1
Over 55	PCU	5	57-70	61.6	4-10	7.2
Composite	PCU	20	44-70	52.4	1-11	5.6

Test 1b: Daytime, Preexisting conditions, Crossing Signals Not Activated

** Lt: Large truck (18 or more wheels), AO: All other vehicles
PCU: Passenger car or pickup truck

\+ Zones 1-3: 2000 feet (610m) to 350 feet (107m) in advance of crossing

* All speeds given in mph; 1mph = 1.6kph.

TABLE A-3
Southern Pacific Railroad Crossing
(Test 2a)

Initial Speed * Category	Vehicle Type **	Sample Size	Initial Speed *		Speed Change* Zones 1-3 +	
			Range	Average	Range	Average
0 - 45	PCU	4	35-44	40.3	0-12	5.3
46 - 55	PCU	4	48-55	51.3	4-24	7.8
Over 55	PCU	3	62-69	64.3	4-15	9.0
Composite	PCU	11	35-69	50.8	0-24	8.6

Test 2a: Nighttime, Preexisting Conditions, Crossing Signals Activated

TABLE A-4
Southern Pacific Railroad Crossing
(Test 2b)

Initial Speed * Category	Vehicle Type **	Sample Size	Initial Speed *		Speed Change* Zones 1-3+	
			Range	Average	Range	Average
0 - 45	PCU	6	41-43	42	1-7	4.2
46 - 55	PCU	7	50-55	52.3	2-14	6.9
Over 55	PCU	4	56-73	65	7-11	8.8
Composite	PCU	17	41-73	51.2	1-14	6.4

Test 2b: Nighttime, Preexisting Conditions, Crossing Signals Not Activated

**Lt: Large Truck (18 or more wheels), AO: All other vehicles
PCU: Passenger car or pickup truck
+Zone 1-3: 2000 feet (610m) to 350 feet (107m)
*All speeds given in mph; 1mph = 1.6kph.

TABLE A-5
Southern Pacific Railroad Crossing
(Test 3a)

Initial Speed * Category	Vehicle Type **	Sample Size	Initial Speed *		Speed Change * Zones 1-3+	
			Range	Average	Range	Average
0 - 45	PCU	5	42-45	43.6	4-8	5.2
46 - 50	PCU AO	4 1	49-54 49	52.3 49	6-8 9	6.8 9
Over 55	PCU	2	58-67	62.5	6-9	7.5
Composite	PCU	11	42-67	50.2	4-9	6.4

Test 3a: Daytime, First Week, AAWD (Signs Only) Installed, Crossing Signals Activated

TABLE A-6
Southern Pacific Railroad Crossing
(Test 3b)

Initial Speed * Category	Vehicle Type **	Sample Size	Initial Speed *		Speed Change * Zones 1-3 +	
			Range	Average	Range	Average
0 - 45	AO PCU Lt	1 2 1	37 34-35 45	37 34.5 45	4 0-7 5	4 3.5 5
46 - 55	Lt PCU	1 8	48 47-55	48 50.8	14 1-19	14 7.6
Over 55	AO PCU	1 2	67 56-59	67 57.5	24 10	24 10
Composite	PCU	12	34-59	49.2	0-19	7.3

Test 3b: Daytime , First Week, AAWD (Signs Only) Installed, Crossing Signals Not Activated

** Lt: Large Truck (18 or more wheels), AO: All other vehicles
PCU: Passenger car or pickup truck
\+ Zones 1-3: 2000 feet (610m) to 350 feet (107m)
* All speeds given in mph; 1mph = 1.6kph.

TABLE A-7
Southern Pacific Railroad Crossing
(Test 4a)

Initial Speed * Category	Vehicle Type**	Sample Size	Initial Speed *		Speed Change * Zones 1-3 +	
			Range	Average	Range	Average
0 - 45	PCU	4	39-45	43.3	4-13	8.5
46 - 55	PCU	5	48-54	51.2	4-11	7.4
Over 55	PCU	3	58-61	59.7	5-12	9.0
Composite	PCU	12	39-61	50.7	4-13	8.3

Test 4b: Nighttime, First Week, AAWD (Signs Only), Installed, Crossing Signals Activated

TABLE A-8
Southern Pacific Railroad Crossing
(Test 4b)

Initial Speed * Category	Vehicle Type **	Sample Size	Initial Speed *		Speed Change * Zones 1-3 +	
			Range	Average	Range	Average
0 - 45	PCU	2	41-43	42	4	4
46 - 55	PCU	6	48-54	50.8	2-8	4.5
Over 55	PCU	6	56-72	61.7	2-8	4.8
Composite	PCU	14	41-72	54.2	2-8	4.6

Test 4b: Nighttime, First Week, AAWD (Signs Only) Installed, Crossing Signals Not Activated.

** Lt: Large truck (18 or more wheels), AO: All other vehicles
PCU: Passenger car or pickup truck
+ Zones 1-3: 2000 feet (610m) to 350 feet (107m)
* All speeds given in mph; 1mph = 1.6kph.

TABLE A-9
Southern Pacific Railroad Crossing
(Test 5a)

Initial Speed * Category	Vehicle Type **	Sample Size	Initial Speed *		Speed Change * Zones 1-3 +	
			Range	Average	Range	Average
0 - 45	PCU	3	38-44	41.0	2-7	3.7
46 - 55	PCU	10	46-55	50.1	1-10	6.2
Over 55	PCU	7	56-68	58.4	2-8	5.2
Composite	PCU	20	38-68	51.7	1-10	5.5

Test 5a: Daytime, Second Week, AAWD (Signs Only) Installed, Crossing Signals Activated

TABLE A-10
Southern Pacific Railroad Crossing
(Test 5a)

Initial Speed * Category	Vehicle Type **	Sample Size	Speed Change by Zone *					
			Zone 1 +		Zone 2 +		Zone 3 +	
			Range	Average	Range	Average	Range	Average
0 - 45	PCU	3	0	0	1-5	2.3	1-2	1.3
46-55	PCU	10	0-5	1.6	0-4	2.2	1-6	2.4
Over 55	PCU	7	0-2	.9	0-4	2.0	1-4	2.3
Composite	PCU	20	0-5	1.1	0-5	2.2	1-6	2.2

**Lt: Large trucks (18 or more wheels), AO: All other vehicles
PCU: Passenger car or pickup truck
+Zone 1: 2000-900 feet (610-274m), Zone 2: 900-550 feet (274-168m)
Zone 3: 550-350 feet (168-107m), Zone 4: 350 feet (107m)-crossing
*All speeds given in mph; 1 mph = 1.6kph.

TABLE A-11
Southern Pacific Railroad Crossing
(Test 5b)

Initial Speed * Category	Vehicle Type **	Sample Size	Initial Speed*		Speed Change * Zones 1-3 +	
			Range	Average	Range	Average
0 -45	PCU Lt	1 2	40 40-43	40 41.5	2 0-2	2.0 1.0
46 - 55	PCU AO Lt	11 1 2	46-55 52 50	51.5 52 50	3-10 2 8	5.7 2.0 8.0
Over 55	PCU	6	56-64	58.8	3-12	7.0
Composite	Lt PCU	4 18	40-50 40-64	45.8 52.7	0-8 2-12	4.5 5.9

Test 5b: Daytime, Second Week, AAWD (Signs Only) Installed, Crossing Signals Not Activated

TABLE A-12
Southern Pacific Railroad Crossing
(Test 5b)

Initial Speed* Category	Vehicle Type**	Sample Size	Speed Change by Zone*					
			Zone 1+		Zones 2 & 3+		Zone 4+	
			Range	Average	Range	Average	Range	Average
0 - 45	Lt PCU	2 1	0.0 0.0	0.0 0.0	0-2 2.0	1.0 2.0	- -	- -
46 - 55	Lt AO PCU	2 1 11	1-3 0.0 0-3	1.5 0.0 1.0	5-7 2.0 1-9	6.0 2.0 4.7	7.0 - 5-14	7.0 (1)++ - 8.2 (6)
Over 55	PCU	6	0-3	1.3	3-10	5.7	0-13	4.2 (5)
Composite	PCU	18	1-10	1-1	4.63	0-14	0-14	6.4 (11)

** Lt: Large trucks (18 or more wheels), AO: All other vehicles
PCU: Passenger car or pickup truck
+ Zone 1: 2000-900 feet (610-274m), Zone 2: 900-550 feet (274-168m)
Zone 3: 550-350 feet (168-107m), Zone 4: 350 feet (107m)- crossing
*All speeds given in mph; 1 mph = 1.6kph.

++ (n): refers to a sub-sample of size n

TABLE A-13
Southern Pacific Railroad Crossing
(Test 6a)

Initial Speed * Category	Vehicle Type**	Sample Size	Initial Speed *		Speed Change* Zones 1-3 +	
			Range	Average	Range	Average
0 - 45	AO PCU	1 3	39 37-45	39 41.0	4 4-5	4 4.3
46 - 55	PCU	7	47-54	50.0	4-14	9.3
Over 55	PCU	4	58-70	64.3	8-21	13.3
Composite	PCU	14	37-70	52.1	4-21	9.4

Test 6a: Nighttime, Second Week, AAWD (Signs Only) Installed, Crossing Signals Activated

TABLE A-14
Southern Pacific Railroad Crossing
(Test 6a)

Initial Speed * Category	Vehicle Type **	Sample Size	Speed Change by Zone *					
			Zone 1 +		Zone 2 +		Zone 3 +	
			Range	Average	Range	Average	Range	Average
0 - 45	AO PCU	1 3	0.0 0-1	0.0 .7	1.0 0-1	1.0 .3	3.0 3-4	3.0 3.3
46 - 55	PCU	7	0-2	.4	2-7	3.4	2-12	5.4
Over 55	PCU	4	0-4	2.5	3-6	4.5	2-18	6.3
Composite	PCU ALL	14 15	0-4 0-4	1.1 1.0	0-7 0-7	3.1 2.9	2-18 2-18	5.6 5.4

** Lt: Large trucks (18 or more wheels), AO: All other vehicles
PCU: Passenger car or pickup truck
+ Zone 1: 2000-900 feet(610-274m), Zone 2: 900-550 feet (274-168m)
Zone 3: 550-350 feet (168-107m), Zone 4: 350 feet (107m)-crossing
*All speeds given in mph; 1 mph = 1.6kph.

TABLE A-15
Southern Pacific Railroad Crossing
(Test 6b)

Initial Speed* Category	Vehicle Type **	Sample Size	Initial Speed *		Speed Change * Zones 1-3+	
			Range	Average	Range	Average
0 - 45	AO PCU	2 3	40-45 37-43	42.5 39.3	7.0 3-4	7.0 3.3
46 - 55	PCU	6	46-55	48.5	3-8	6.2
Over 55	PCU	5	56-65	59.2	3-16	8.4
Composite	PCU	14	37-65	50.4	3-16	6.4

Test 6b: Nighttime, Second Week, AAWD (Signs Only) Installed, Crossing Signals Not Activated

TABLE A-16
Southern Pacific Railroad Crossing
(Test 6b)

Initial Speed * Category	Vehicle Type **	Sample Size	Speed Change by Zone *					
			Zone 1 +		Zones 2 & 3+		Zone 4 +	
			Range	Average	Range	Average	Range	Average
0 - 45	AO PCU	2 3	2-3 0.0	2.5 0.0	4-5 3-4	4.5 3.3	3.0 0-10	3.0(2)++ 5.0(2)
46 - 55	PCU	6	0-4	1.0	3-7	5.2	1-6	3.7(3)
Over 55	PCU	5	0-1	.8	3-15	7.6	-5-13	2.4(5)
Composite	PCU All	14 16	0-4 0-4	.6 .8	3-15 3-15	5.6 5.8	-5-13 -5-13	3.2(10) 3.2(12)

** Lt: Large trucks (18 or more wheels), AO: All other vehicles
PCU: Passenger car or pickup truck
+ Zone 1: 2000-900 feet (610-274m), Zone 2: 900-550 feet (274-168m)
Zone 3: 550-350 feet (168-107m), Zone 4: 350 feet (107m)-crossing
* All speeds given in mph; 1 mph = 1.6kph.
++ (n): refers to a sub-sample of size n.

TABLE A-17
Southern Pacific Railroad Crossing
(Test 7a)

Initial Speed * Category	Vehicle Type **	Sample Size	Initial Speed *		Speed Change * Zones 1-3 +	
			Range	Average	Range	Average
0 - 45	PCU	1	44	44	6	6
46 - 55	Lt PCU	1 7	54 48-54	54 51.3	24 7-23	24 13.1
Over 55	PCU	3	56-65	59.0	15-26	19.7
Composite	PCU	11	44-65	52.7	6-26	14.3

Test 7a: Daytime, Second Week, AAWD Installed, AAWD and Crossing Signals Activated

TABLE A-18
Southern Pacific Railroad Crossing
(Test 7a)

Initial Speed * Category	Vehicle Type **	Sample Size	Speed Change by Zone *					
			Zone 1 +		Zone 2 +		Zone 3 +	
			Range	Average	Range	Average	Range	Average
0 - 45	PCU	1	1.0	1.0	3.0	3.0	2.0	2.0
46 - 55	Lt PCU	1 7	9.0 0-9	9.0 2.6	8.0 1-7	2.0 3.9	13.0 3-14	13.0 6.7
Over 55	PCU	3	5-8	6.0	1-9	3.7	6-12	10.0
Composite	PCU	11	0-9	3.4	1-9	3.7	2-14	7.2

** Lt: Large trucks (18 or more wheels), AO: All other vehicles
PCU: Passenger car or pickup truck
+ Zone 1: 2000-900 feet (610-274m), Zone 2: 900-550 feet (274-168m)
Zone 3: 550-350 feet (168-107m), Zone 4: 350 feet (107m)-crossing
* All speeds given in mph; 1 mph = 1.6kph.

TABLE A-19
Southern Pacific Railroad Crossing
(Test 8a)

Initial Speed * Category	Vehicle Type **	Sample Size	Initial Speed *		Speed Change * Zones 1-3 +	
			Range	Average	Range	Average
0 - 45	PCU	3	31-45	39.3	8-12	9.7
46 - 55	PCU	7	46-52	47.4	6-28	16.9
Over 55	PCU	7	58-70	63.0	7-40	23.3
Composite	PCU		31-70	52.4	6-40	18.2

Test 8a: Nighttime, Second Week, AAWD Installed, AAWD and Crossing Signals Activated

TABLE A-20
Southern Pacific Railroad Crossing
(Test 8a)

Initial Speed * Category	Vehicle Type **	Sample Size	Speed Change by Zone *					
			Zone 1 +		Zone 2 +		Zone 3 +	
			Range	Average	Range	Average	Range	Average
0 - 45	PCU	3	1-2	1.7	1-9	4.0	2-5	4.0
46 - 55	PCU	7	0-4	2.0	1-20	8.1	4-11	6.7
Over 55	PCU	7	0-21	8.3	0-15	7.3	1-10	8.1
Composite	PCU	17	0-21	4.5	0-20	7.06	1-11	7.1

** Lt: Large trucks (18 or more wheels), AO: All other vehicles
PCU: Passenger car or pickup truck
+ Zone 1: 2000-900 feet (610-274m), Zone 2: 900-550 feet (274-168m)
Zone 3: 550-350 feet (168-107m), Zone 4: 350 feet (107m)-crossing
* All speeds given in mph; 1 mph = 1.6kph.

TABLE A-21
Southern Pacific Railroad Crossing
(Test 8b)

Initial Speed * Category	Vehicle Type **	Sample Size	Initial Speed *		Speed Change* Zones 1-3 +	
			Range	Average	Range	Average
0 - 45	PCU	4	40-43	42.0	2-8	5.8
46 - 55	PCU	3	49-54	51.7	5-9	6.7
Over 55	PCU	3	57-61	59.0	2-8	5.3
Composite	PCU	10	40-61	50.0	2-9	5.9

Test 8b: Nighttime, Second Week, AAWD Installed, No Signals Activated

TABLE A-22
Southern Pacific Railroad Crossing
(Test 8b)

Initial Speed * Category	Vehicle Type **	Sample Size	Speed Change by Zone*					
			Zone 1 +		Zones 2 & 3 +		Zone 4 +	
			Range	Average	Range	Average	Range	Average
0 - 45	PCU	4	0-1	.3	2-8	5.5	2-7(3)++	2.7
45 - 55	PCU	3	0-4	1.7	5	5.0	5-6(2)	5.5
Over 55	PCU	3	0-1	.7	2-7	4.7	0-6	3.3
Composite	PCU	10	0-4	.8	2-8	5.1	0-7(8)	3.2

** Lt: Large trucks (18 or more wheels), AO: All other vehicles
PCU: Passenger car or pickup truck
+ Zone 1: 2000-900 feet (610-274m), Zone 2: 900-500 feet (274-168m)
Zone 3: 550-350 feet (168-107m), Zone 4: 350 feet (107m)-crossing
++ (n): refers to a sub-sample of size n.
*All speeds given in mph; 1 mph = 1.6kph

TABLE A-23
Santa Fe Crossing (Test 1a)

Initial Speed * Category	Vehicle Type**	Sample Size	Vehicle Speed Change Profile*				
			Initial Speed Range	ZONE 1+ Speed Change		ZONE 2 + Speed Change	
				Range	Average	Range	Average
0 - 55	PCU	1	49	1.0	1.0	1.0	1.0
Over 55	PCU Lt	2 6	62-74 58-66	0-3 1-5	1.5 2.7	1.0 0-3	1.0 1.5
Composite	PCU	3	49-74	0-3	1.3	1.0	1.0

Test 1a: Daylight, Preexisting Conditions, Crossing Signals Activated

TABLE A-24
Santa Fe Crossing (Test 1b)

Initial Speed * Category	Vehicle Type **	Sample Size	Vehicle Speed Change Profile*				
			Initial Speed Range	ZONE 1+ Speed Change		ZONE 2 + Speed Change	
				Range	Average	Range	Average
0 - 55	AO PCU	1 2	55 51-54	0.0 0-4	0.0 2.0	1.0 0-2	1.0 1.0
Over 55	PCU	9	58-68	1-7	1.9	0-4	1.0
Composite	PCU	11	51-68	0-7	1.9		1.0

Test 1b: Daylight, Preexisting Conditions, Crossing Signals Not Activated

**PCU= Passenger Car Unit, Lt= Large Truck (18 wheels or more), AO= All Other Vehicles

+ZONE 1= Terminal Point: 1000 ft (305m) in advance of crossing

ZONE 2= Terminal Point: 500 ft (252m) in advance of crossing

*All speeds given in mph; 1 mph = 1.6kph.

TABLE A-25
Santa Fe Crossing (Test 2a)

Initial Speed * Category	Vehicle Type **	Sample Size	Vehicle Speed Change Profile*: Initial Speed Range	ZONE 1+ Speed Change: Range	ZONE 1+ Speed Change: Average	ZONE 2 + Speed Change: Range	ZONE 2 + Speed Change: Average
0 - 55	PCU	2	48-53	0-2	1.0	6-10	8.0
Over 55	AO PCU	2 10	58-62 56-67	2-3 0-9	1.5 2.1	8-10 3-25	9.0 11.1
Composite	PCU	12	48-67	0-9	1.9	3-25	10.6

Test 2a: Nighttime, Preexisting Conditions, Crossing Signals Activated.

TABLE A-26
Santa Fe Crossing (Test 2b)

Initial Speed* Category	Vehicle Type **	Sample Size	Vehicle Speed Change Profile*: Initial Speed Range	ZONE 1 + Speed Change: Range	ZONE 1 + Speed Change: Average	ZONE 2 + Speed Change: Range	ZONE 2 + Speed Change: Average
0 - 55	PCU Lt	1 6	48 51-55	0.0 0-7	0.0 2.0	0.0 1-3	0.0 1.7
Over 55	PCU Lt	5 11	56-70 57-66	0-2 0-15	.8 3.4	0-7 0-9	1.4 3.2
Composite	PCU Lt	6 17	48-70 51-66	0-2 0-15	.7 2.9	0-7 0-9	1.2 2.7

Test 2b: Nighttime, Preexisting Conditions, Crossing Signals Not Activated

**PCU= Passenger car unit; Lt= Large truck (18 or more wheels); AO= All other vehicles
+Zone 1 Terminal Point: 1000 ft (305m) in advance of crossing
Zone 2 Terminal Point: 500 ft (252m) in advance of crossing
*All speeds given in mph; 1 mph = 1.6kph

TABLE A-27
Santa Fe Crossing (Test 4a)

Initial Speed* Category	Vehicle Type **	Sample Size	Vehicle Speed Change Profile*				
			Initial Speed Range	ZONE 1+ Speed Change		ZONE 2+ Speed Change	
				Range	Average	Range	Average
0 - 55	PCU	4	47-55	0-2	.5	6-16	10.3
	AO	2	42-50	0.0	0.0	5-6	5.5
	Lt	1	53	0.0	0.0	6.0	6.0
Over 55	PCU	9	57-67	0-5	.8	2-14	8.0
	AO	2	57-60	1-5	3.0	7-19	13.0
Composite	PCU	13	47-67	0-5	.7	2-16	8.7
	AO	4	42-60	0-5	.7	5-19	9.3

Test 4a: Nighttime, AWWD (Signs Only) Installed
Crossing Signals Activated

TABLE A-28
Santa Fe Crossing (Test 4b)

Initial Speed* Category	Vehicle Type **	Sample Size	Vehicle Speed Change Profile*				
			Initial Speed Range	ZONE 1 + Speed Change		ZONE 2 + Speed Change	
				Range	Average	Range	Average
0 - 45	PCU	4	47-53	0-1	.5	0-4	2.0
	Lt	10	46-55	0-2	.6	0-5	2.0
Over 45	PCU	4	56-66	0-1	.3	0-5	2.5
	Lt	5	56-60	0-5	1.4	0-8	2.4
Composite	PCU	8	47-66	0-1	.4	0-7	2.3
	Lt	15	46-60	0-5	.9	0-8	2.1

Test 4b: Nighttime, AAWD (Signs Only) Installed,
Crossing Signals Not Activated

+ ZONE 1: Terminal Point: 1000 ft (305m) in advance of crossing
ZONE 2: Terminal Point: 500 ft (252m) in advance of crossing

** PCU= passenger car unit, Lt= large truck (18 wheels or more)
AO= All other vehicles

*All speeds given in mph; 1 mph = 1.6kph.

TABLE A-29
Santa Fe Crossing (Test 5a)

Initial Speed Category	Vehicle Type	Sample Size	Vehicle Speed Change Profile*				
			Initial Speed Range	ZONE 1 + Speed Change		ZONE 2 + Speed Change	
				Range	Average	Range	Average
0 - 55	AO PCU	1 5	51 49-53	0.0 0-3	0.0 .6	0.0 0-4	0.0 .8
Over 55	PCU	8	56-75	0.0	0.0	0.0	0.0

Test 5a: Daytime, AAWD (Signs Only) Installed
Crossing Signals Activated

TABLE A-30
Santa Fe Crossing (Test 7a)

Initial Speed Category	Vehicle Type	Sample Size	Vehicle Speed Change Profile*				
			Initial Speed Range	ZONE 1 + Speed Change		ZONE 2 + Speed Change	
				Range	Average	Range	Average
0 - 55	AO PCU	1 6	54 50-54	0.0 0-7	0.0 1.8	2.0 1-5	2.0 2.3
Over 55	PCU	8	56-69	0-6	3.1	0-12	4.3
Composite	PCU	14	50-69	0-7	2.5	0-12	3.4

Test 7a: Daytime, AAWD (With Lights) Installed, AAWD and Crossing Signals Activated.

\+ ZONE 1 Terminal Point: 1000 ft(305m) in advance of crossing
ZONE 2 Terminal Point: 500 ft(252m) in advance of crossing
** PCU= passenter car unit, Lt= large truck (18 or more wheels), AO= All other vehicles
* All speeds given in mph; 1 mph = 1.6kph.

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FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.

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