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REPORT 470

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

Traffic-Control Devices for Passive Railroad-Highway Grade Crossings

TRANSPORTATION RESEARCH BOARD

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Traffic-Control Devices for Passive Railroad-Highway Grade Crossings

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SUBJECT AREAS
Highway Operations, Capacity, and Traffic Control

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Staff
Transportation Research Board

This report presents an evaluation of traffic-control devices to improve the behavior of drivers when approaching and crossing a passive railroad-highway grade crossing (i.e., one without signals or gates). In addition to a review of the literature, the report includes a comprehensive analysis of the tasks drivers face at a passive grade crossing. Those responsible for signing and evaluating safety at grade crossings will find the report informative as will those interested in human factors in safety. A key audience for the report will be those responsible for *the Manual on Uniform Traffic Control Devices* (*MUTCD*) because it is intended that the recommendations be considered for the next edition.

Although crashes at railroad-highway grade crossings have been significantly reduced over the past 30 years, automobile-train crash fatalities continue to be a serious traffic safety concern. The *MUTCD* provides guidance on what traffic-control devices should be used at grade crossings. Much research has been conducted and is underway to determine the effectiveness of standard and alternative grade-crossing traffic-control devices. Although many studies have included good experimental designs to evaluate devices, others have not. The validity of some studies is also suspect because of inappropriate statistical tests or inadequate control for biases. As a result, questions remain on the effectiveness of current *MUTCD* devices, and the results of most of the studies have not been incorporated into the *MUTCD*.

Based on perceived shortcomings in the standard *MUTCD* grade-crossing traffic-control devices and the results of some research studies, transportation agencies across the United States have implemented a wide variety of modifications to the standard devices (e.g., "Ohio Buckeye," retroreflective patterns on crossbuck posts, Yield to Trains and Look for Trains signs, and rumble strips on approaches). Such modifications have contributed to the inconsistency of grade-crossing treatments across the United States.

Under NCHRP Project 3-57, Westat, with their subcontractor BMI, critically evaluated the literature and previous research and identified promising traffic-control devices. They thoroughly described appropriate driver behavior when approaching and crossing railroad tracks and the results of inappropriate behavior. Based on this analysis, they selected traffic-control devices to evaluate further using driver focus groups and comprehension testing. An expert panel confirmed the results and identified implementation issues.

The report summarizes the research conducted and recommends changes to the *MUTCD*. Barriers to implementation are discussed as well as the desirability of using Stop signs at all passive grade crossings. Recommendations for further research are presented.

The *MUTCD* is recognized as the national standard for traffic-control devices on all public roads. This report should not be considered to supplant the *MUTCD*.

CONTENTS

AUTHOR ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 3-57, "Recommended Traffic-Control Devices for Railroad-Highway Grade Crossings," by Westat and BMI. Westat was the prime contractor for this study. Neil D. Lerner, Manager of Human Factors, Westat, was the principal investigator. The other authors of this report are Robert E. Llaneras, Senior Research Scientist, Westat; Hugh W. McGee, Principal, BMI; and Donald E. Stephens, Senior Transportation Engineer, BMI.

The research team received valuable contributions throughout the project from three consultants: Gerson J. Alexander, Positive Guidance Applications, Inc.; Archie C. Burnham, Archie Burnham and Associates; and Bernard L. Morris, railroad safety consultant.

TRAFFIC-CONTROL DEVICES FOR PASSIVE RAILROAD-HIGHWAY GRADE CROSSINGS

SUMMARY

The *Manual on Uniform Traffic Control Devices* (*1*) provides guidance on what traffic-control devices (TCDs) should be used at rail-highway grade crossings. Previous studies have called into question the effectiveness of current practices, and various alternatives have been put forth. The objective of this project was to determine whether any innovative or nonstandard TCDs could be recommended as improvements to safety at passive (i.e., no flashing lights or automatic gates) rail-highway grade crossings. The focus was on low-cost treatments that could be widely implemented.

The project evaluated the shortcomings of current practice and the potential benefits of alternative devices through a variety of activities. These activities included a critical review of recent research on grade-crossing TCDs and alternatives, a detailed driver task analysis to describe appropriate and inappropriate driver behavior and associated information requirements when approaching and traversing an at-grade crossing, driver focus groups, empirical evaluations of comprehension and preference for alternative TCDs, and an expert workshop to critically review promising alternatives.

The work identified key requirements that a TCD system for passive rail-highway grade crossings should meet and for which the current system is lacking or does not communicate well. The present system does not adequately convey to many drivers that (1) there is no active warning system, (2) the onus for detecting approaching trains is on the driver, (3) there is a “yield” regulatory situation in effect, and (4) site factors exist that may influence the proper approach speed. There are additional problems concerning crossing or crossbuck conspicuity, the timeliness of information, the public belief regarding the meaning and application of current devices, uniformity and predictability of other traffic actions, and risk perception.

Based on the requirements of an effective TCD system for passive crossings, an alternative was recommended. The alternative retains the current primary TCDs (i.e., R15-1 crossbuck and W10-1 highway-rail grade crossing advance warning sign) as system elements but supplements the elements with additional TCDs that clarify the intended messages and address other current shortcomings. The proposed system has three primary components: (1) an at-crossing sign assembly that indicates a specific regulatory control condition; (2) a railroad advance warning sign assembly, which discriminates active and passive crossings; and (3) a provision for warnings regarding specific site factors,

where appropriate (to be located between the crossing and the railroad advance warning sign assembly). The normal (i.e., default) treatment of a passive crossing would involve yield control, and the crossing sign assembly includes incorporation of a Yield sign with the crossbuck. Stop control would be used only under warranting conditions. The proposed highway-rail grade crossing advance warning sign assembly uses the current W10-1 advance warning sign comounted with a supplemental sign that indicates the nature of the regulatory control at the crossing. Although the suggested alternative TCD system provides a better match to key requirements than does current practice, the project also identified a number of implementation issues that will need to be addressed if the recommendations are to be adopted.

CHAPTER **1**

INTRODUCTION AND OVERVIEW OF APPROACH

1.1 BACKGROUND

Rail-highway grade crossings are potential points of conflict between roadway traffic and trains. The train has right-of-way in these conflicts, and it is the driver's responsibility to yield to the train. The system of traffic-control devices (TCDs) located at a crossing is intended to aid the driver in carrying out this responsibility. At a *passive* rail-highway grade crossing, the traffic-control system does not inform roadway users of the approach or presence of trains, locomotives, or railroad cars. This passive system is in contrast to *active* rail-highway grade crossing traffic control systems, such as flashing light signals or automatic gates. Roughly one-half of the United States' approximately 3,500 highway-rail incidents (and approximately 400 related fatalities) occur at passive crossings. There are 90,000 passive public rail-highway grade crossings in the United States, many of which are characterized by low-train or low-traffic volumes. Because of the costs involved in installing and maintaining upgraded levels of crossing control (i.e., flashing lights, automatic gates, grade separation), it is not feasible to upgrade many of these sites. Therefore, there is a need to identify relatively low-cost improvements to TCD practice at passive grade crossings that will promote safer driver behavior and result in safety benefits.

There have been substantial gains made in the past 30 years in safety at rail-highway grade crossings. Thirty years ago, the United States suffered about 1,500 fatalities a year at crossings. That number is nearly four times the current number, despite the greatly increased traffic volumes seen today. However, this reduction has come about largely through improvements to the level of grade-crossing control, as well as through improvements to active warning devices. For those at-grade crossings that still have only passive TCDs, there has been no clear improvement in driver behavior or crash experience. Many previous reports over this 30-year period, beginning with *NCHRP Report 50: Factors Influencing Safety at Highway-Rail Grade Crossings* (*2*), identified limitations to standard practice in terms of meeting driver information needs. Yet, practice for signing and delineation of passive crossings has remained essentially unchanged, and inappropriate driver behavior continues to be a problem.

Research studies and field experience have shown that drivers (1) frequently fail to comply with TCDs at rail-highway grade crossings, (2) do not have good comprehension of the meaning and implications of TCDs, and (3) do not understand risks and responsibilities associated with passive crossings. Existing TCD practice may not be providing the driver with the information required, in optimal form, where and when it is needed. Improvements to signs and markings may foster more appropriate driver behavior at passive rail-highway grade crossings. In response to this concern, a variety of suggested improvements to current practice have been put forth in recent years—for example, a more routine use of Stop signs at passive rail-highway grade crossings, modifications to improve the conspicuity of the crossbuck, incorporation of the Yield message into TCDs, discrimination in advance signing between passive- and active-crossing types, and the use of supplemental message plates to encourage improved visual search. Some suggested treatments have been subjected to empirical or analytical evaluation; others have not. The validity of those studies that have been conducted is sometimes questionable. Although there is a concern over the effectiveness of current practice, the effectiveness of alternative approaches is also at issue. Furthermore, there is a concern that local modifications to TCDs or practices may contribute to the inconsistency of grade-crossing treatments across the United States.

1.2 OBJECTIVES

The objective of NCHRP Project 3-57, "Recommended Traffic-Control Devices for Railroad-Highway Grade Crossings," was to determine whether any innovative or non-standard TCDs could be recommended as improvements to safety at passively signed rail-highway grade crossings. The focus was on low-cost treatments that could be widely implemented. It is intended that the recommendations be made to the National Committee on Uniform Traffic Control Devices (NCUTCD) and FHWA for consideration in future revisions of the *Manual on Uniform Traffic Control Devices* (*MUTCD*) (*1*).

1.3 RESEARCH APPROACH

The project included a critical evaluation of recent research and recommendations, collection of new information, and formal analytical activities. However, the scope of the project was not sufficient to permit actual formal field evaluation of the suggested devices.

The project consisted of the following sequence of tasks:

- **Task 1—Critical Evaluation of Research:** Identify and critically evaluate pertinent research results regarding railroad–highway grade crossing TCDs.
- **Task 2—Describe and Classify Appropriate and Inappropriate Motorist Behavior and Consequences:** Formally analyze the appropriate and inappropriate behavior of drivers at railroad–highway grade crossings and relate this to driver information requirements and to resulting consequences.
- **Task 3—Describe Promising TCDs:** Based on the previous tasks, identify promising TCDs and consider their likely effects and costs.
- **Task 4—Interim Report and Evaluation Plan:** Summarize the findings and prepare a workplan to evaluate possible new or modified TCDs.
- **Task 5—Evaluate TCD Concepts:** Conduct the evaluations in accordance with the work plan.
- **Task 6—Final Report and Implementation Plan:** Develop formal recommendations; summarize the methods and findings of the project in a final report; and include an implementation plan that describes the activities that will promote the implementation of the recommendations.

This report presents the methods and results of the work conducted and describes recommended enhancements to TCD practice at railroad–highway grade crossings.

CHAPTER 2

APPROACH AND FINDINGS

This chapter presents the highlights of the technical activities that led to the TCD recommendations in Chapter 3. The sequence of activities included (1) evaluation of research, (2) analysis of driver behavior and information needs, (3) identification of promising TCDs, (4) conduct of driver focus groups, (5) comprehension testing of potential TCDs, and (6) conduct of an expert workshop to critically review findings and preliminary recommendations. For each of these technical activities, there is a description of the approach and a summary of the primary findings. Additional detail is provided in the appendix to this report.

2.1 EVALUATION OF RESEARCH

2.1.1 Research Review: Objective, Scope, and Method

The initial task of the project provided a comprehensive critical review of recent research related to TCDs for passive railroad-highway grade crossings. The full report on this effort was provided as a project interim report (*3*). The interim report provided a review and evaluation of available research results based on the applicability and conclusiveness of findings on various railroad-highway grade crossing TCDs. The review focused on passive grade crossings and the TCDs appropriate to them. The search and review was conducted in the second half of 1999 and emphasized work conducted since 1989.

There have been numerous past reviews of driver behavior at grade crossings and of the effectiveness or limitations of various TCDs in improving that behavior. These reviews include several comprehensive reviews, beginning with the influential review and analysis by Schoppert and Hoyt in *NCHRP Report 50* (*2*). This report was subsequently followed by major reviews by Sanders, Kolsrud, and Berger (*4*); Knoblauch, Hucke, and Berg (*5*); and Lerner, Ratte, and Walker (*6*). Other useful reviews with more restricted foci also have been performed. The present review took these past literature evaluations as a starting point and focused on work conducted since the Lerner et al. report. Some pre-1989 articles were included either because they were not included or not fully discussed in the previous work or because they were central to the evaluation. For the most part, however, the emphasis was on the evaluation of research concerning TCD effectiveness conducted over the 1989-to-1999 period. Previous reviews and research reports already provided a reasonably good understanding of driver requirements and the limitations or problems of current TCD design and practice. The need here was to evaluate whether any proposed countermeasures provide meaningful improvements.

The search for relevant research reports included many different activities:

- Automated keyword searches of primary databases (e.g., NTIS, TRIS);
- Internet searches;
- Contents scans of key journals, books, and proceedings;
- Contacts with key offices at FHWA, the Federal Railroad Administration, and the Volpe Center;
- Requests for information on relevant research or practice from all states;
- A presentation to the Highway Railroad–Crossing Subcommittee of NCUTCD, and a request for information or contacts on past or current evaluations;
- Requests through relevant professional committees (e.g., TRB); and
- Contacts with leading researchers.

Each relevant article was independently reviewed by multiple reviewers in order incorporate a range of expertise and relevant perspectives—for example, a traffic engineer and a human factors researcher might each review a study of advanced warning signs. These reviews were critical evaluations rather than simply descriptive ones and followed a common format so that the insights of multiple reviewers could be readily integrated into a single combined assessment. Each review began with a descriptive section, which included the bibliographic citation, brief description of objective and approach, author's abstract, and summary of the author's statement of major findings and conclusions. The second (and primary) portion of each individual review was the critical assessment section. This section had primary subtopics of experimental design and methods, samples, measures, and analysis and interpretation. Within each subtopic, the reviewers had check-off items to ensure a complete critical assessment. The final section of each review presented the reviewer's summary and conclusions, including limitations, concurrence with other research findings or practice, and key unanswered questions.

The review was organized around related types of TCDs and the problems they address—for example, modifications to the crossbuck sign related to its daytime effectiveness are treated in one section. Crossbuck reflectorization treatments related to nighttime or poor visibility–condition viewing are treated in another section. Additional informational signage located at the crossing (in addition to the crossbuck) is treated in yet another section. A given research article might include multiple devices or issues and so is discussed within each appropriate section.

For each section of the review, the discussion was broken into three subsections. Subsection 1 summarized the status of what was known about the device and topic, prior to 1990, based on previous reviews. The summaries were distilled from major reviews from 1968 through 1989. In addition, conclusions from other substantive reviews subsequent to 1989 were also included particularly for their reviews and assessments of pre-1990 research. Using the primary source, newer research cited in these more recent reviews was independently reviewed. The more recent review documents included reviews under FHWA's project on "Improved Traffic Control Devices at Rail-Highway Grade Crossings" (e.g., [*7*]) and the National Transportation Safety Board (NTSB) study of passive grade crossings (*8*).

Subsection 2 for each problem reviewed more recent research. Individual studies or other relevant activities were described and critically discussed. In Subsection 3, after discussing the new research and considering it with past findings, conclusions regarding the state of knowledge and demonstrated TCD effectiveness were drawn.

2.1.2 Research Review: Findings and Conclusions

The full literature review provided in the interim report contains extensive and detailed discussion for each category of TCD (*4*). This section provides a summary of the major findings.

Table 1 summarizes the major findings for each device type. For each category of TCD, the table indicates the expected or purported impact on driver behavior and then summarizes the findings and conclusions of the related research.

Although conclusions regarding specific TCDs can be found in the body of the report and Table 1, general points can also be made. One of the more striking and disappointing points is how little appears to be known definitively (or is even reasonably well supported) by empirical data on TCD effectiveness. The literature deals with limited issues, and the research on these issues usually suffers from methodological shortcomings. There have been relatively few studies of substantial scope in the past decade that have included passive crossing treatments as their primary focus. In a 1989 review, Lerner et al. (*6*) pointed out that the problems of driver behavior at passive rail-highway grade crossings, as well as most of the "innovative" alternatives to current practice that might address such problems, were described in the analysis of Schoppert and Hoyt in 1968 in *NCHRP Report 50* (*2*). Little progress regarding these alternatives had occurred since 1968; the present review must echo Lerner et al.'s conclusion more than a decade later. *NCHRP Report 50* is more than 30 years old, and the field is still discussing many of the same issues and possible countermeasures.

Among the issues of current interest for passive crossings is the use of Stop or Yield signs. Part of this interest has been spurred by a recent report by NTSB (*8*), which recommended much broader use of Stop signs at railroad-highway grade crossings. The literature evaluation found a great deal of controversy but questionable empirical basis on this issue. There are differences of opinion regarding the use of Stop signs at passive grade crossings: don't use at all (*9*), use only under certain conditions (*10–12*), and use at all passive crossings unless hazardous (*8*). The primary reason for nonuse or limited use appears to be concern over the high level of noncompliance, which is indicated by a high percentage of drivers failing to come to a complete stop. Three independent studies observed that the percentages of drivers not coming to a complete stop were high and higher than the percentages found at highway intersections. This high level of noncompliance is equated to disrespect for the Stop sign that might increase and carry over to other locations if the Stop sign is used indiscriminately. NTSB apparently did not share that concern because it recommends use of the sign unless the usage is deemed unsafe by an engineering study. The primary reason for using a Stop sign appears to be limited sight distance. Some feel that if there is a limited corner sight triangle as the driver approaches the crossing, a Stop sign should be used so that the driver—recognizing that there is a need to stop—will at least slow down significantly, allowing him or her to come to a stop safely if necessary. Others will argue that a Stop sign should not be deployed merely to achieve this driver behavior. Other concerns remain with the use of Stop signs—for example, the anticipated higher incidence of vehicle-vehicle crashes, notably rear-end types. Research evaluating this concern is very limited. Any further evaluation of the Stop sign should examine this issue comprehensively.

In summary, despite the selective practice of using Stop signs at some grade crossings for many years and despite several field studies, the effectiveness of Stop signs for general use appears unresolved and controversial. Existing data do not support firm recommendations.

In contrast to Stop signs, Yield signs have not been frequently deployed at rail-highway grade crossings, and field data are minimal. However, with regard to the use of the standard Yield sign or incorporating a Yield message into sign systems for a passive grade crossing, there appears to be a growing feeling that this Yield usage may be desirable. Nearly all who have written on this topic have concluded that the cross-

TABLE 1 Summary of literature review findings and conclusions on TCDs

TCD	Purpose/Expected Driver Impacts	Findings/Conclusions
Crossbuck Design and Meaning • Conrail shield • Ohio Buckeye • Changes in color, border	• Increased sign conspicuity to improve detection and recognition of crossing. • Enhanced comprehension of requirements and responsibilities. • Slower approach speeds and better search.	• Drivers generally aware standard crossbuck relates to rail-highway crossing, but confused about precise meaning. Drivers do not have clear understanding of responsibilities when encountering passively protected crossing. • Conrail shield and Buckeye crossbuck may provide more salient cues to driver in the form of a Yield message at the crossing. • Some research suggests drivers may slow more in response to the Conrail shield, but new crossbuck designs do not provide for behavior that is substantially safer than does standard crossbuck. • Other than driver preference, none of the work in the past decade convincingly shows that improved designs bring about improved conspicuity or driver behavior. • Use of different contrasting colors, backgrounds, and borders has yielded mixed results.
Reflectivity • Reflectorization scheme • Rear of crossbuck • Post: face, rear, side • Roadside delineators • Train-headlight reflection	• Increased conspicuity of crossing at night. • Addition of highly reflective material to the sides of the posts is intended to enable the posts to be visible from skewed-angle approaches. • Better perception of location (vs. floating crossbuck). • Better detection of train in crossing (flicker effect).	• Reflectorizing the back of crossbucks appears an effective means to alert drivers to presence of a train at the track via flicker effects. • Systems with retroreflective tape running the full length and along the front and back of the posts appears to increase conspicuity and enable drivers to determine where the railroad tracks intersect the roadway. • Guidelines and recommendations for reflectorization exist, but need to be validated. • Photometric studies reveal that reflectorized posts and crossbucks have higher luminance levels than does the standard crossbuck under nighttime conditions. • Some reflectorization treatments appear to have significant long-term improvements in both driver- looking behavior and deceleration rates. • Roadside delineators are promising in designating approach; optimal pattern and spacing not yet determined. • Additional field tests need to be conducted before assessing the effectiveness of reflectivity treatments activated by a train's headlights. Initial work is encouraging.
Intersection TCDs • Stop sign • Yield message • Yield sign	• Better comprehension of responsibility. • Greater slowing, better search.	• Stop sign reduces speeds, indications of better search. • Relatively poor compliance with Stop at rail crossings. • Generalized "disrespect" unknown. • Stop sign net safety benefits unproven, especially for general use. • Yield message improves driver comprehension. • Yield sign not field evaluated.
Information at Crossing • Crossing angle • Look for trains • Number of tracks • Australian width marker assembly	• To convey some additional item of information that is important at the point of the crossing to the driver. • Crossing to the driver conspicuity.	• Effectiveness of currently used signs (number of tracks, exempt) unknown, but suspect. • Crossing angle sign more typically suggested as advance sign. • "Look for Trains" sign apparently under consideration by FHWA, but no empirical evaluation for use at crossing.
Active vs. Passive Advance • Train icon	• Inform driver of type of crossing since responsibility differs at each. • Improve speed control and visual search. • Counteract misbelief that all crossings are active.	• Repeated recommendations based on analytic grounds, but little empirical basis. • Common distinction in foreign practice; no empirical evaluation found. • Little empirical work on either comprehendible icons or behavioral and safety effects.

(*continued on next page*)

TABLE 1 (*Continued*)

TCD	Purpose/Expected Driver Impacts	Findings/Conclusions
Advance Sign Information • Look for train • Crossing angle • Speed-related • Sight distance • Train speed • Distance to crossing	• Alert drivers to the presence of a crossing. • Communicate crossing information (special hazards or requirements). • Guide driver information–processing and vehicle-control activities.	• Argument for use of these signs is primarily on logical grounds; very little scientific support available for their effectiveness. • No significant impact on approach speeds or driver-looking behavior found for the "Look for Trains" sign; however, studies are methodologically weak or flawed. • Very few studies directly comparable in their treatments; some use stand-alone signs, others use combination systems. • Use of signs related to visual search might merit consideration since this represents a real limitation in driver behavior. • European countries use advance signs to code distance to crossing, but few systematic tests of their effects on driver behavior exist or have been reported. • Effectiveness of these signs may depend on the physical characteristics of the crossing.
Vehicle-Activated Signal • Strobe • Flashing signal	• Increase conspicuity of advance sign at night.	• Supplemental lighting systems (flashers and strobes) may attract driver attention, but can also cause drivers to become confused about meaning of the lights (i.e., whether they indicate the presence of a train). • Benefits in terms of looking behavior, speeds, or safety unclear. • No clear picture has emerged with respect to whether vehicle-activated strobes or flashers cause adverse driver reactions. No extreme reactions evident, but some evidence of increased risk or unsafe practices. • If not properly designed, lights can make reading the sign itself difficult.
Pavement Marking • "RXR" layout • Stop line/ hazard zone	• Redundant cue to presence and location of crossing. • Indication of hazard zone.	• Little attention, discussion or empirical, directed at this issue. • Recent FHWA consideration of pavement treatment to delineate hazard zone, but no empirical evaluation.
Surface Treatment • Rumble strip • Pavement color, surface	• Direct driver attention to presence of hazard area, need for slowing.	• No empirical evaluations found.

buck does not convey the intended message. Although drivers associate the crossbuck with a grade crossing, too many do not understand what is required of them. Because what is required of the driver is to yield to an oncoming train, many feel a Yield message should be provided. Existing studies indicate that the Yield sign conveys this message more effectively than does a crossbuck, although the studies are seriously flawed. What remains to be more thoroughly examined is how the Yield sign should be incorporated at passive grade crossings to achieve long-term improved driver behavior.

The traffic community is concerned about both Stop- and Yield-sign use at rail-highway grade crossings because it is feared that widespread use at rail crossings may diminish respect for these signs at roadway intersections. This diminished respect will be an extremely difficult hypothesis to evaluate empirically, and the outcome may be influenced by enforcement and education strategies that accompany implementation.

Another issue that has been the subject of recent discussion is the need to discriminate passive from active grade crossings in the advance-signing treatment. Currently, all crossings have the same advance warning sign and pavement markings. The only distinction is the actual presence of the active device (i.e., lamps or gates) at the point of the crossing itself. The argument made by previous reviewers remains convincing: the driver needs to know on the approach to a crossing that the crossing is passively protected. Yet, current TCD practice does not provide this information. U.S. practice stands in contrast to practice in other countries, which conveys this information through advance warning sign icons. However, there still does not appear to be a formal evaluation of the effectiveness of distinct advance warning signs in promoting safer driver behavior at passive crossings. The literature is not clear on the best way to indicate the type of crossing. Little work has been done on this issue over the past decade although the problem of information ambiguity is frequently raised. Approaches that do not use different advance warning signs for active and passive crossings, but rather add additional information items when there is a passive crossing, represent another strategy.

Although this review did find limitations to recent empirical research on passive-crossing TCDs, the nonempirical discussions, analyses, and activities suggested that there now may be receptiveness to some of the ideas that have been proposed for some time. Examples include treatments such as distinguishing active from passive crossing advance signing, the use of Yield signs or the Yield message at the crossing, and the use of more direct information regarding appropriate driver behavior.

2.2 ANALYSIS OF DRIVER BEHAVIOR AND INFORMATION NEEDS

2.2.1 Objective and Scope

This section documents the results of a task analysis to describe and classify appropriate and inappropriate driver behavior when drivers approach and cross a rail-highway grade crossing. Driver information needs and sources, errors, and behavioral outcomes resulting from this analysis were used to provide an objective basis for the evaluation and screening of suggested TCDs and approaches. The primary product of this task is summarized in Table 2. The discussion highlights some of the findings; details are contained in the tabled results.

Past analyses and classifications of driver behavior (*2, 4, 6,* and *13*) have been useful but relatively superficial. One major limitation of past classifications of driver behavior at rail-highway crossings is that the classifications have been too generic. Driver information requirements and appropriate and inappropriate behaviors are often situational, and thus consideration of all aspects that could make a difference in driver behavior is needed to fully understand driver decision-making and error processes. Previous work has also tended to provide idealized descriptions of driver actions with little emphasis on actual observed behaviors. This idealization has made it difficult to target problems and to identify their underlying causes. The current effort used a highly structured set of formal and interrelated analytic procedures to describe driver behavior on the approach to and negotiation of passive rail-highway crossings. Although a single composite scenario was used in this analysis, detailed information relating to individual site, driver, and environmental variables was examined, thereby providing a means to capture fine-grained details. This analysis also sought to specify actual driver behavior and factors that affect behavior. Information extracted from these analyses served as the primary basis for gathering relevant task requirements, describing and classifying appropriate and inappropriate driver behavior, and identifying likely problems and their consequences.

2.2.2 Approach

Task analytic techniques were used to provide a basis for assessing appropriate and inappropriate driver behaviors, classifying human error, and identifying consequences. Our approach employed several task analysis methods to ensure that the objective task properties, requirements, and performance-shaping factors associated with driver behavior at rail-highway crossings are represented while emphasizing those aspects that potentially make a difference in driver behavior. This approach leads to a fuller and more complete understanding of the operational environment and underlying issues that affect driver performance and was accomplished by implementing the following process:

1. Reviewing existing literature to identify operational requirements, potential crossing-site factors, and typical driver actions;
2. Selecting a representative operational scenario to capture the full range of factors present in the environment;
3. Performing a task analysis to describe driver-performance requirements, information needs, information sources, and requisite knowledge and skills; and
4. Describing and classifying appropriate and inappropriate driver behaviors and their consequences.

Literature was reviewed to gather task-related information, identify potential performance-shaping factors (e.g., crossing, driver, environmental, roadway, and vehicle characteristics), and uncover observational research outlining actual driver behavior. Information requirements and behaviors associated with a given approach phase, expressed in terms of the information handling zones outlined by Post, Alexander, and Lunenfeld (*14*), was captured using this basic approach. A single high-level composite scenario was developed and served as the basis for these analyses. Relevant aspects of a particular situation that influence driver behavior, decision-making and performance were captured and specified by defining performance-shaping factors. This approach enabled key influences (e.g., driver familiarity, day versus night, limited versus unlimited sight distance, etc.) to be represented and analyzed without the need to develop endless numbers of low-level scenarios.

Tasks were decomposed, via task analytic methods, into their basic elements relating to driver information needs; information sources; requisite knowledge, abilities, and skills; and action requirements. Driver behavioral requirements in the form of idealized behaviors were related to intrinsic task properties and underlying human abilities, skills, and knowledge in order to identify possible conflicts or unrealistic behavioral requirements that exceed drivers' abilities—for example, skewed-angle crossings can pose a challenge for older drivers who, as a group, have limited head-and-neck flexibility, which makes it exceedingly difficult for them to search as they near the track. It may also be difficult, if not

TABLE 2 Task analysis of passive rail-highway crossings

PHASE	DRIVER INFORMATION REQUIREMENTS		DRIVER ACTION REQUIREMENTS AND DECISIONS		LIKELY PROBLEMS/ CONSEQUENCES (INAPPROPRIATE BEHAVIORS)	PERFORMANCE-SHAPING FACTORS	POTENTIAL COUNTERMEASURES
	INFORMATION NEEDS	*INFORMATION SOURCES*	*KNOWLEDGE/ SKILLS/ABILITY REQUIREMENTS*	*ACTION REQUIREMENTS (APPROPRIATE BEHAVIORS)*			
Advance Approach Zone	a) **Presence of a crossing ahead.** b) **Crossing type** (passive or actively protected).	a) **Standard advance warning sign** (placed b/n 850 and 100 ft from the crossing depending on posted speed limit); pavement markings or crossbuck. b) **Experience with crossing, direct view of crossing** (noting the *absence* of information or signals).	a) **Knowledge of crossing and meaning of the advance warning sign or pavement markings.** Drivers generally understand the sign is associated with a crossing, but do not understand its behavioral implications *(6)*. b) **Responsibility for detecting trains must be understood.** Many drivers assume all crossings are actively protected *(6)*.	▪ **Search for signs/trains** (eye scanning, minimal head movement). ▪ **Prepare to adjust vehicle speed** (speed selection).	▪ **Failure to detect crossing ahead resulting in late recognition of train.** Need to improve driver understanding of the need to search. Only 35% of drivers look in both directions *(7)*. ▪ **Failure to recognize crossing as passive.** The absence of active warning is a factor that drivers must recognize and interpret. Drivers may be unable to discern the type of crossing until they are in the nonrecovery zone *(17)*. If a driver does not anticipate a passive crossing, choice of speed and search strategies may not be appropriate.	▪ **Night vs. day.** Identifying the presence of a crossing is more difficult at night. ▪ **Driver expectancy.** Influences what drivers see, how they interpret information, and what risks they are willing to assume. Expectancy affects the speed and accuracy of performance. ▪ **Conspicuity of TCDs.** ▪ **Familiarity.** Drivers not familiar with the crossing and associating the advance warning sign with active warning devices will not recognize the need to search *(18)*. ▪ **Presence of other vehicular traffic.** If drivers slow unexpectedly to read the advance warning sign, this may increase risk of vehicle-to-vehicle rear-end accidents.	▪ **Induce appropriate slowing and search behaviors.** – Alert drivers to the presence of a *passively* protected crossing ahead. Standard advance warning signs do not differentiate between active and passive crossings. – Increase TCD conspicuity (e.g., vehicle activated lights, sign color, shape, background contrast, etc).

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TABLE 2 (*Continued*)

PHASE	DRIVER INFORMATION REQUIREMENTS		DRIVER ACTION REQUIREMENTS AND DECISIONS		LIKELY PROBLEMS/ CONSEQUENCES (INAPPROPRIATE BEHAVIORS)	PERFORMANCE-SHAPING FACTORS	POTENTIAL COUNTERMEASURES
	INFORMATION NEEDS	*INFORMATION SOURCES*	*KNOWLEDGE/ SKILLS/ABILITY REQUIREMENTS*	*ACTION REQUIREMENTS (APPROPRIATE BEHAVIORS)*			
Approach Zone	a) **Location, distances and number of tracks at crossing ahead.** b) **Sight limitations.** c) **Train present or approaching crossing.** d) **Train speed, distance, and direction.** e) **Appropriate approach speed.**	a) **Standard crossbuck sign, direct view of crossing and tracks.** b) **Direct view of obstructions.** c) **Direct view of locomotive, headlights, or railcars, train whistle.** In daytime, under good visibility and sight conditions, the train provides all information needed for drivers to make a decision to act. d) **Direct view of train.** e) **Posted speeds,**	a) **Knowledge of crossing. Ability to detect and interpret crossbuck information, or view the crossing.** b) **Ability to detect the presence of visibility restrictions. Knowledge of the need to search, and search range and direction.** Most drivers appear insensitive to sight restrictions. c) **Ability to detect and recognize train. Ability to detect acoustic signal, and localize the sound. Ability to determine whether train is in**	▪ **Search and acquire needed information.** ▪ **Make go/no go decision.** If no immediate action taken, the driver continues to search for trains and is prepared to slow or stop. Uniform Vehicle Code requires drivers to stop only if a train is an immediate hazard or in hazardous proximity to the crossing. ▪ **If lateral site distance is restricted, approach speed should be reduced.** ▪ **Maintain vehicle lane position, separation from traffic,**	▪ **Failure to process and apply acquired information.** ▪ **Recognition errors at passive crossings are frequent (77 to 85%).** Late recognition of trains already at the crossing accounts for 22 to 25% of all accidents *(13)*. Between 15 and 35% of drivers do not look for trains at all. ▪ **Decision errors.** – *Go/No Go.* Decision errors underlie many train-vehicle collisions *(13)*. Breakdowns in higher-order perceptual processes (closing rate judgments or required stopping distance) contribute to these errors. Drivers are not aware of how inaccurate judgments are and tend to underestimate required braking distance, particularly under wet/icy road conditions.	▪ **Limited sight distance or obstructions.** Drivers must realize their view of the track is restricted and adjust approach behavior accordingly. 31 to 36% of drivers may not detect the train due to limited sight distance *(13)*. Drivers engage in more search behaviors earlier in the approach following improvements to sight distance, but also tend to increase approach speeds *(19)*. ▪ **Crossing familiarity**. Familiar drivers are likely to have higher approach speeds *(20)* and be aware of prevailing sight-distance problems. Driver expectancy that no train will be present increases chance of detection error. This expectancy is strong since many drivers only look in one direction along the tracks. Unfamiliar drivers tend to look more frequently than do familiar drivers.	▪ **Induce appropriate slowing and search behaviors.** – Advise drivers of appropriate approach speeds or the need to slow via signage, rumble strips, etc. – Instruct drivers where to search. The effectiveness of Look for Trains signs mounted as supplemental panels or stand-alone signs is not fully documented. – Guide driver search behavior, noting crossing geometry/angle. – Warn drivers of high-speed trains (traveling above 80 mph). ▪ **Minimize barriers to adequate search.** – Alert drivers of potential or existing sight limitations,

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TABLE 2 (*Continued*)

PHASE	DRIVER INFORMATION REQUIREMENTS		DRIVER ACTION REQUIREMENTS AND DECISIONS		LIKELY PROBLEMS/ CONSEQUENCES (INAPPROPRIATE BEHAVIORS)	PERFORMANCE-SHAPING FACTORS	POTENTIAL COUNTERMEASURES
	INFORMATION NEEDS	*INFORMATION SOURCES*	*KNOWLEDGE/ SKILLS/ABILITY REQUIREMENTS*	*ACTION REQUIREMENTS (APPROPRIATE BEHAVIORS)*			
		other vehicle behavior, grade crossing, road geometry.	**hazardous proximity to the crossing or poses an immediate hazard.** d) **Ability to judge relative train speed from eye movements or train profile and headlights.** e) **Ability to judge closing speed, predict time of arrival to track, make appropriate decisions.**	**etc.** ▪ **Anticipate actions of other vehicles, particularly lead vehicles if present.**	– *Failure to select appropriate approach speed.* Only about 5% of drivers reduce their approach speed by more than 6 mph with no sight restrictions; this number increases to 15% with major restrictions *(18)*. ▪ **Driver distraction** (because of other attention demands), leading to missed detections. ▪ **Misjudge train speed or distance.** Large objects appear to move slower than smaller objects (large object illusion). Lack of depth cues can also contribute to this problem. Misjudgments tend towards underestimating speed or overestimating distance, which may lead to riskier decisions. ▪ **Inappropriate risk perception.** Driver's perceived risk	▪ **Night vs. day**. Identifying crossing location and estimating the location and rate of travel of a locomotive are more difficult at night. Incidence of vehicle-strikes-train collisions is higher at night than in daylight *(21)*. Drivers tend to underestimate the speed of a train at night. ▪ **Crossing angle**. Visual search is more difficult at acute angle crossings. About 80% of crossings in the United States have angles between 60 and 90 degrees. About 4% have angles less than 30% *(22)*. This creates problems for drivers with limited neck and torso flexibility. ▪ **Expected delays and annoyance**. Slowing or stopping represents a disruption of normal driving that can be annoying. Research demonstrates that many drivers have exaggerated estimates of the length of a typical	rough crossing, etc. – Minimize information overload and distractions. ▪ **Raise awareness of risk.** – Accident analyses reveal that in most cases, there is clear indication of train approach and adequate visibility *(23)*. Motorists have a low perceived risk of an accident at passive crossings. – Enforcement. ▪ **Enhance driver's estimate of the safe time interval to cross.** – Aid sensory and perceptual capabilities in making judgments: vehicle's distance from crossing, train speed and distance, etc.

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TABLE 2 (*Continued*)

PHASE	DRIVER INFORMATION REQUIREMENTS		DRIVER ACTION REQUIREMENTS AND DECISIONS		LIKELY PROBLEMS/ CONSEQUENCES (INAPPROPRIATE BEHAVIORS)	PERFORMANCE-SHAPING FACTORS	POTENTIAL COUNTERMEASURES
	INFORMATION NEEDS	*INFORMATION SOURCES*	*KNOWLEDGE/ SKILLS/ABILITY REQUIREMENTS*	*ACTION REQUIREMENTS (APPROPRIATE BEHAVIORS)*			
					at crossing may be low given the low-probability event of a train approaching or present at the crossing. Chances of missing a train are increased if driver assigns a low probability to the event (presence of train). Experience at highway intersections where approaching traffic can compensate for any misperceptions may lead to overly risky decisions at rail crossings.	delay. Both may lead to riskier decisions. ▪ **Competing inputs, crossing geometry, rough surface**. Attention must be shared with driving, surrounding traffic, other signage, etc. The actual crossing is a feature that attracts attention and competes with search for trains. ▪ **Train speed**. Lower-speed trains are more difficult to detect at the crossing at night than are higher-speed trains. ▪ **Expectancy**. Recognition is influenced by driver expectancy. Low expectancy of a train increases detection time. ▪ **Age and sex**. Strongly related to accident involvement are sex and age; males, young and old drivers are over represented.	

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TABLE 2 (*Continued*)

PHASE	DRIVER INFORMATION REQUIREMENTS		DRIVER ACTION REQUIREMENTS AND DECISIONS		LIKELY PROBLEMS/ CONSEQUENCES (INAPPROPRIATE BEHAVIORS)	PERFORMANCE-SHAPING FACTORS	POTENTIAL COUNTERMEASURES
	INFORMATION NEEDS	*INFORMATION SOURCES*	*KNOWLEDGE/ SKILLS/ABILITY REQUIREMENTS*	*ACTION REQUIREMENTS (APPROPRIATE BEHAVIORS)*			
Non-recovery Zone	a) **Train's speed and distance from the tracks.** b) **No train in vicinity of crossing.** c) **Vehicle's speed and distance from the tracks.** d) **Location of appropriate stop point.**	a) **In daytime under good visibility and sight conditions, the train provides all the information needed.** b) **Drivers observe the crossing and surrounding area (for absence of train).** c) **Speedo-meter and visual references used to gauge vehicle speed**. **Distance to track via direct observation or experience**.	a) **Ability to judge relative train speed and distance from eye movements, train profile, or headlights.** b) **Ability to Scan**. May require significant head and torso flexibility. Australia limits head movements for scanning at crossings (110 degrees to the left, and 140 degrees to the right). c) **Ability to judge relative speed and distance.** d) **Ability to detect pavement markings and judge closing speed and distance.**	▪ **Train approaching or at crossing.** – Driver should immediately slow and come to a complete stop within 50 feet of the crossing but not less than 15 feet from the nearest rail. ▪ **If no train present.** – Driver should slow, continue to search, and cross tracks.	▪ **Incorrect action resulting from a lack of understanding**. A majority of drivers believe the appropriate behavior is to stop at the tracks and look *(24)*. Very few actually do this. ▪ **Lack of attention, inadequate sight distance, or excessive speed**. These may result in an imminent crash situation, requiring the driver to take evasive action (steer left or right to avoid hitting the train at the tracks). ▪ **Errors in judgment made during approach**. If a train is detected, the driver must decide to either stop before reaching the crossing, or attempt to beat the train to the crossing. This decision is based on several factors: train speed and distance to crossing, and vehicle speed and distance to crossing, etc. Misjudgments could	▪ **Nighttime**. Cues to the crossing, the traffic control device, or the train itself are difficult to detect at night. Supplemental information may be required to make a proper decision. ▪ **Presence of other vehicular traffic.** ▪ **Environmental conditions.** ▪ **Multiple tracks.** ▪ **Sight distance.** ▪ **Crossing illumination.** ▪ **Train speeds**. Slow- or fast-moving train approaching or crossing. ▪ **Vehicle class**. Commercial trucks have different operating characteristics than do passenger vehicles. Some vehicles required to stop at all crossings.	▪ **Improve detection of train and tracks (increase conspicuity).** – Increase conspicuity of crossbucks. The standard white-and-black crossbuck has limited conspicuity, particularly when viewed against a white background. – Reflectorization to increase nighttime conspicuity of crossbuck. Motorists appear to cross the tracks with a greater safety margin when crossings are equipped with fully reflectorized crossbucks or the Buckeye crossbuck *(25)*. – Reflectorizing the backs of crossbucks is recommended as a means to alert drivers to the presence of a train at the track via "flicker effects." The effectiveness of

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TABLE 2 (*Continued*)

PHASE	DRIVER INFORMATION REQUIREMENTS		DRIVER ACTION REQUIREMENTS AND DECISIONS		LIKELY PROBLEMS/ CONSEQUENCES (INAPPROPRIATE BEHAVIORS)	PERFORMANCE-SHAPING FACTORS	POTENTIAL COUNTERMEASURES
	INFORMATION NEEDS	*INFORMATION SOURCES*	*KNOWLEDGE/ SKILLS/ABILITY REQUIREMENTS*	*ACTION REQUIREMENTS (APPROPRIATE BEHAVIORS)*			
		d) **Pavement marking (stop line).**			lead to incorrect decisions. ▪ **Drivers may fail to judge a railroad crossing sign as significant and may not attend to the message.** ▪ **Deceleration exhibited at crossings may be a function of the perceived roughness of the grade crossing.** Increased likelihood of rear-end collisions may result. ▪ **Deceleration because of late recognition of physical impediments could increase crossing time, reduce margin of safety.**		this treatment will likely vary as a function of train speed. – Lower the standard height of crossbucks Although the *MUTCD* specifies crossbucks be placed so that the sign center is 9 feet from the ground, recent evidence suggests this may be too high to be effectively illuminated by the average automobile *(26)*. – Addition of reflectorized material to all four sides of crossbuck posts to enable the posts to be visible from skewed angle approaches. – Train reflectorization. – Clarify the "2 Train" problem message.

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TABLE 2 (*Continued*)

Phase	Driver Information Requirements		Driver Action Requirements and Decisions		Likely Problems/ Consequences (Inappropriate Behaviors)	Performance-Shaping Factors	Potential Countermeasures
	Information Needs	*Information Sources*	*Knowledge/ Skills/Ability Requirements*	*Action Requirements (Appropriate Behaviors)*			
							▪ **Specify appropriate behavior.** – The standard crossbuck sign conveys an ambiguous message. No specific behavioral response is communicated to the driver. Many motorists adopt a "stop, look, and listen" rule that could lead to increased rear-end collisions *(6* and *7)*. – Use of Stop signs cause greater slowing and more looking for trains, but have relatively low compliance rates in terms of complete stops. ▪ **Provide redundant information.** – Provide information about crossing density and traffic volume. – Distance to crossing.

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TABLE 2 (*Continued*)

PHASE	DRIVER INFORMATION REQUIREMENTS		DRIVER ACTION REQUIREMENTS AND DECISIONS		LIKELY PROBLEMS/ CONSEQUENCES (INAPPROPRIATE BEHAVIORS)	PERFORMANCE-SHAPING FACTORS	POTENTIAL COUNTERMEASURES
	INFORMATION NEEDS	*INFORMATION SOURCES*	*KNOWLEDGE/ SKILLS/ABILITY REQUIREMENTS*	*ACTION REQUIREMENTS (APPROPRIATE BEHAVIORS)*			
							– On his or her approach, inform the driver where to look. – Advisory speed plate.
Hazard Zone	a) **Physical crossing difficulties** (roughness, hump, geometry). b) **Visibility distance up the tracks and clearance at the crossing.** c) **Number of tracks, and existence of multiple trains.**	a) **Direct view of crossing, prior experience.** b) **Direct view of tracks.** c) **Supple-mental Plate on crossbuck, direct view of track and trains.**	a) **Ability to recognize implications of features** (rough crossing). b) **Ability to search,** neck-and-torso flexibility. **c) Knowledge that multiple trains may be crossing in close proximity.**	▪ **If stopped, awaiting train to cross.** – Once train clears the crossing, search both directions for additional trains and cross the tracks when appropriate. ▪ **If no train in vicinity.** – Adjust speed to crossing surface conditions. – Verify there are no trains present or approaching. – Cross the tracks.	▪ **Many drivers initiate looking behavior in the hazard zone**, which may not allow enough time to avoid a potential collision *(7)*. ▪ **Differential vehicle behavior** (slowing, stopped) ,leading to increased vehicle-vehicle collisions. ▪ **Stalled at crossing.** ▪ **Deceleration because of late recognition of physical impediments** could increase crossing time, reduce margin of safety, and increase rear-end collisions between vehicles.	▪ **Crossing alignment**. Vertical and horizontal curvature can reduce a driver's view of a train. Hump crossings are also problematic. ▪ **Vehicle type**. Hump crossings pose problems for large vehicles such as trucks with trailers. ▪ **Presence of vehicular traffic**.	▪ **Delineating the hazard area.** – Clearly delineate hazard zone – Use stop line to designate appropriate location for a stop. – Use of reflectorized crossbucks and roadside delineators to identify where the railroad track intersects the roadway. ▪ **Minimize vehicle control demands for negotiating crossing.**

impossible, for drivers to make appropriate speed judgements as they approach the track in the absence of very long sight distances. Other types of limitations and potential conflicts were similarly identified using this technique.

Unlike previous models or task descriptions, our analysis also incorporated data on what drivers actually do when approaching and traversing passive grade crossings (i.e., behavioral descriptions), rather than merely stating what drivers are expected to do. This process was strictly analytic, relying heavily on the published literature, and involved no direct observation of driver behavior. Accident data and published reports of driver behavior, however, were readily available. This information served two purposes: (a) it enabled comparisons between idealized and actual performance, and (b) it provides insights into the specific problems being encountered and potential countermeasures.

Descriptive schemes were used to guide the type of information collected and the manner in which tasks were described, defined, and classified and to classify driver behaviors, as well as problems and consequences. A classification scheme developed by Berliner, Angell, and Shearer (*15*) was used to classify driver behaviors into five basic activities: (1) searching for and receiving information; (2) identifying objects, actions, or events; (3) information processing; (4) decisionmaking and problem solving; and (5) motor processes. Knoblauch et al.'s (*5*) driver behavioral model used a similar type of classification scheme to describe driver behavioral requirements (e.g., sensory detection, perception, analytic operations, decisionmaking, and control response). Berliner et al.'s (*15*) model was used because it captures these same types of processes and provides exemplar behaviors to ensure accurate and reliable classification. This taxonomy allowed driver behaviors to be described in terms of basic underlying processes, providing a mechanism for identifying common or related activities, as well as aiding in the identification of countermeasures. Using this approach, not only can countermeasures be targeted to specific processes, but common sets of underlying deficiencies also can be identified and remedied as a group using a specific class or type of countermeasure. Similar frameworks were used to classify problems and consequences using Reason's (*16*) basic error groupings (e.g., recognition errors, decision errors, and action errors, etc.). Consequences of inappropriate behaviors were cast in terms of safety and, where possible, supported by descriptions of observed driver behavior gathered from the literature.

To summarize, driver information needs, performance requirements, performance-shaping factors (e.g., site, driver, and environmental characteristics), and problems and consequences were identified by reviewing literature on driver behavior at highway-rail crossings and applying task analysis techniques. A task analysis was conducted to identify major requirements and problem areas and to provide a basis for specifying potential countermeasures by allowing relationships among these factors to be identified.

2.2.3 Findings

Results are documented in Table 2. For each driving phase associated with approaching and negotiating a passively protected rail-highway crossing, the table identifies driver information needs; information sources; knowledge, skills, and abilities; action requirements; likely problems and consequences; performance-shaping factors; and potential countermeasures. Four phases or information zones are defined (Figure 1) and correspond to those identified by Post et al. (*14*). These zones help to define the types, amount, and location of information drivers need. With one exception, noted below, these zones are differentiated on the basis of stopping sight distance (i.e., the distance required to stop, including the time required to make the decision and implement the action) and decision sight distance. As such, the zones are a function of

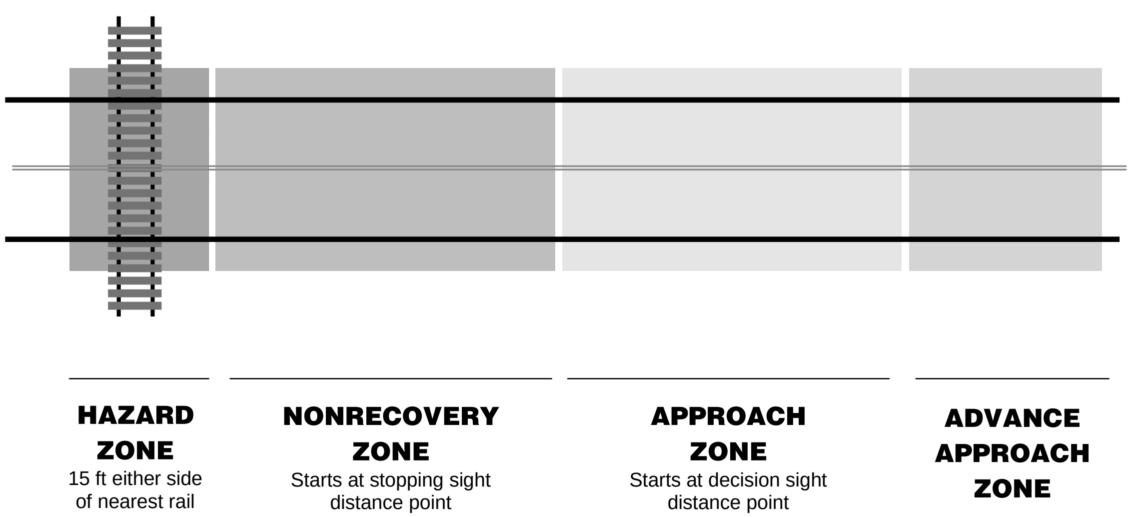

Figure 1. Approach zones.

vehicle approach speeds, vehicle capabilities, and driver reaction time and do not correspond to physical locations along the site. These zones may be different for different drivers or situations.

In Table 2, the final column—which lists potential countermeasures—is not intended to be exhaustive, nor is there any indication that these approaches are necessarily recommended. More critical evaluation and recommendation occur at other stages of this project. The set of potential countermeasures in the table illustrates a mapping of potential TCDs to selected problems identified in the table.

2.2.3.1 Advance Approach Zone

In the advance approach zone, drivers are not yet directly affected by potential hazards (e.g., train crossing), but should become alerted to potential upcoming hazards (e.g., crossing ahead) so they can better anticipate or respond to the possible threat. The advance information required by the driver depends on the nature of the crossing. In the case of actively protected crossings, drivers do not need to recognize the hazard, but rather do need to recognize the warning and respond appropriately. Providing drivers with advance information about the type of crossing ahead (e.g., passive) not only alerts them to the presence of a rail-highway crossing, but also prepares them to assume responsibility for their own safety and sets the stage for what to expect. As indicated in Table 2, these two information elements are critical at this stage because they build driver expectancy, which in turn plays a significant role in driver perception and ability to access and use available information. Expectancy can influence what drivers see, how they interpret information, what risks they are willing to assume, and what response alternatives appear appropriate. When drivers receive the information they expect from the environment, performance tends to be fast and error free. Performance may be slow, inaccurate, or inappropriate when expectancies are violated (which increases the time required to detect and recognize a train, for example). Information communicated to the driver during the advance approach zone can effectively enhance the driver's ability to detect and recognize a hazard, as well as respond to it. Currently, drivers have no advance means of ascertaining whether a given crossing is passively or actively protected; this is a particularly difficult challenge for those unfamiliar with the crossing.

2.2.3.2 Approach Zone

Once in the approach zone, drivers need to detect and recognize the hazard, decide on a course of action, and begin to implement the appropriate maneuvers (e.g., begin to slow, maintain speed, speed-up, etc.). Drivers use this zone to search for a train and decide on the proper course of action. Drivers are not required to stop unless a train poses an immediate hazard or is in hazardous proximity to the crossing. If a driver detects the presence of the crossing and an approaching train, high-order perceptual judgements about a train's speed, distance, and closing rate are needed in order to make these judgments. Driver decision errors play an important role in safety at passive rail-highway crossings. Failure to appropriately process and apply acquired information can lead to risky decisions, collisions, or both. The majority of decision errors are made by drivers in moving cars—relatively few accidents occur because a stopped driver misjudges the temporal gap at the crossing and then proceeds. Thus, providing drivers access to relevant information is critical at this stage. Drivers may not have enough time or information to make the right decision. Among the key pieces of information needed to support driver decisions are information about track location and distance; sight limitations; and train speed, distance, and direction. Sometimes accidents also occur as the result of a chain of poor decisions that are made during the approach. Lerner et al. (*6*) note two important consequences to consider in this regard. First, safety interventions at any point in the chain may have some impact, even if the primary decision error occurred at some other point. Second, it may be difficult to discourage drivers to make a decision that involves breaking a sequence of planned actions. Once a driver decides to try to beat the train, it may be difficult to change his or her course of action. A number of factors also influence the accuracy and reliability of driver decisions. As noted in Table 2, drivers tend to underestimate the required braking distance, particularly when roads are wet and icy. Familiar and unfamiliar drivers often behave differently at crossings. Sanders et al. (*4*) found that looking behavior and speed reductions were inversely related to the frequency of crossing use. Drivers may also have difficulty judging the speed, distance, and closing rate of a train, particularly at night.

2.2.3.3 Nonrecovery Zone

The nonrecovery zone defines the point at which drivers cannot safely avoid the hazard without resorting to emergency avoidance maneuvers. It starts at the stopping–sight distance point. Once in the nonrecovery zone, drivers must already be in the process of implementing their speed and path-selection decision. If a train is approaching or is present at the crossing, the driver must stop before entering the hazard zone. Errors in judgement made during the approach phase (e.g., train speed, closing distance, distance to crossing, etc.) may result in an imminent crash situation requiring the driver to take evasive action to avoid colliding with the train.

2.2.3.4 Hazard Zone

The hazard zone defines the area in which vehicles are in physical danger of colliding with a train that is either approaching or at the crossing. Unlike the other zones, this area is defined spatially: 15 ft on either side of the nearest rail at the crossing. Once in this zone, drivers should be safely completing their maneuvers in order to avoid the hazard (e.g., stop or cross). Pavement markings and signs are used to delineate this area and to aid drivers in this regard. Although drivers should still be maintaining their search for trains, research suggests that many drivers do not initiate their search until they are within the hazard zone. Drivers also appear insensitive to the risks of multitrack crossings Although the number of tracks is indicated by a supplemental plated on the crossbuck, drivers generally do not know why this information is important (*4*) and fail to make the direct connection between the number of tracks at the crossing and the possibility of two trains crossing in proximity.

2.2.4 Conclusions

Two basic principles and some general observations emerged from this analysis. The first principle is that drivers need to know and fully understand that when approaching a passively protected rail-highway crossing, the responsibility for accident avoidance rests entirely with them. Unlike at actively protected crossings, drivers are solely responsible for their own safety at passive grades. Because the responsibility is different for active versus passive crossings, drivers need to be made aware that they are approaching a passive crossing and that the decision to stop or proceed rests in their hands. Drivers need to know when the onus is on them to make a decision. This distinction in driver responsibility according to crossing type is currently not very apparent, nor well understood by all drivers. The second principle addresses the need to equip drivers with the appropriate decision aids to ensure the drivers are making the correct decision. When there are information limitations or maneuver problems of any sort at a crossing, drivers must be provided with adequate information to support their decisions. Critical—and particularly relevant when problems with crossings exist (e.g., limited site distance, obstructions, rough crossings, elevated crossings, etc.)—are aids that help drivers acquire and apply information; detect, recognize, and interpret hazards; and make judgments. Drivers must have access to sufficient information to enable them to make correct decisions.

The following major requirements were also revealed as part of this analysis:

- Drivers must understand the need to search.
- The approach must induce appropriate slowing and search behaviors so that drivers know when and how much to slow, as well as where and when to search.
- Barriers to adequate search must be minimized, including reducing attention conflicts that compete for the driver's attention (e.g., traffic, rough crossings, off-roadway distractions, up-road signals, etc.). Drivers must be alerted to any problems in searching for and acquiring information (e.g., sight-distance limitations, skewed crossings, etc.).
- Improvements to assist drivers in meeting their responsibilities are needed. Drivers are not getting enough relevant information that translates into overt action. Information is not being communicated in a direct and usable form. This often results in confusion about a sign's meaning or about the action required.

Given that no single type of error appears to account for the vast majority of accidents at rail-highway grade crossings (*13*), no simple solution is likely to address all or most of these problems. Various kinds of errors, scenarios, and performance-shaping factors underlie vehicle-train collisions. Potential countermeasures, listed in Table 2 and addressed as part of this work, attempt to overcome underlying deficiencies revealed by exploring relationships among driver information needs; knowledge, skills, and abilities; information sources; site characteristics; and performance-shaping factors. This approach enables the locus of the problem to first be specified; solutions targeting deficiencies can then result. Although the principles specified above can aid in identifying appropriate remedies, it is important to note that some problems, particularly those relating to familiar drivers, are not easily solved using passive techniques.

2.3 PROMISING TCDS

2.3.1 Background

After completion of the critical examination of the literature and the conduct of the analysis of driver behavior and information needs, consideration was directed toward promising TCDs. The intent was to identify and provide an initial evaluation of promising approaches prior to proceeding with the subsequent research activities. As stated in the project's research problem statement, this task was envisioned as follows:

> Based on the Task 1 evaluation, describe promising railroad highway grade-crossing TCDs, discuss their likely effect on driver behavior and crashes (particularly in the long term if compliance is likely to decrease with familiarity), and estimate their life-cycle costs. Of particular interest are Stop signs and Yield signs used at crossings and advance warning signs that distinguish between active (e.g., signals, gates) and passive crossings (only signs and markings).

The initial step for this task was to conduct a workshop involving key members of the study team and the NCHRP project monitor. At this workshop, the results from Task 1: Critical Evaluation of Research Literature and Task 2: Motorist Behavior Analysis were reviewed. Emerging from the discussions and assessment of the two task results was a recommendation for a system of "promising traffic control devices" for passive grade crossings.

It was the consensus of the participants that there were certain key information requirements that a driver needs upon approaching and traversing a passive grade crossing, namely

1. That there is a railroad-grade crossing ahead.
2. That the crossing is not protected by bells, lights, or gates (i.e., is a passive crossing) and, therefore, it will be up to the driver to determine whether the train is at or in proximity of the crossing.
3. What actions are required of the driver in approaching and traversing the crossing (i.e., maintain speed or slow down, look for trains, and possibly stop).
4. If appropriate, that there is some special condition or situation at the crossing (e.g. a skewed crossing, limited sight distance, a humped crossing, or high-speed trains) that requires more driver attention and will influence the action described in third item above.

It was apparent from the research literature and driver-behavior analysis that the current system of TCDs used at passive grade crossings fails to meet these information requirements adequately. The literature also provides suggestions for alternative TCDs that have promise to address current shortcomings. However, it was noted that none of these suggestions are well developed and adequately empirically evaluated.

The question of how the essential information is best presented, in both device type and location, as the driver approaches and traverses the crossing was discussed by the study team with a resulting recommendation.

Although the arguments supporting the initial determination of promising TCDs were based on only the initial tasks of the project, it will be seen that subsequent tasks provided additional information that supported these conclusions. The findings of the subsequent tasks also resulted in more specific recommendations. The methods and findings of subsequent tasks are described in Sections 2.4, 2.5, and 2.6, and 3.0.

2.3.2 Promising TCDs

Several promising TCD concepts were identified as a means to address the shortcomings of the current system of marking passive grade crossings. These were viewed as *complementary* devices because together they will function to meet the driver needs. However, although the literature and analysis allowed a determination of the *type* of device that might be beneficial, it did not allow more precise specification of the design of that device. For example, although it was determined that there should be unique advance signing to distinguish passive from active crossings, it is not clear whether it would be best to develop two new signs (active and passive), to develop one new sign (for only active or only passive), or to use the current sign with some form of supplemental panel. For any of these, the specific sign-icon concept and graphic design are unknown; therefore, the promising TCDs were presented as TCD concepts, not specific designs. Specific details of design and placement were developed later on the basis of subsequent project tasks.

The promising devices considered are the following:

1. A Yield sign or Yield message panel, possibly with a supplemental To Trains plaque, to be used at the crossing.
2. A Stop sign in place of a Yield sign under warranting conditions.
3. A revised or enhanced railroad advance warning sign (i.e., a supplemental plaque) that informs the driver of the type of crossing (i.e., active or passive).
4. A device or devices to warn the driver that there is a special condition at the crossing that makes it more hazardous or places additional requirements on the driver.

Table 3 provides an overview of these promising devices. It describes the application, indicates the driver need that the device addresses, and notes outstanding issues regarding design or application. A description of each promising device follows.

2.3.2.1 Yield Sign or Yield Message

As the sole regulatory device at the point of the crossing, the crossbuck suffers a number of limitations that could be addressed by use of the Yield message.

1. The standard crossbuck (i.e., *MUTCD* sign R15-1) does nothing more than indicate the presence of a crossing. It does not inform the driver that the crossing is without active warning devices and therefore the driver has the entire responsibility for detecting and avoiding the train; crossbucks are used at all crossings, active and passive. Substantial numbers of drivers believe that all crossings have active warnings, so informing drivers of the absence of active control is essential.
2. The crossbuck does not indicate the proper action the driver should take. At a passive crossing, the crossbuck functions essentially as a Yield sign, but the appropriate driver response is not as well understood as a Yield message.
3. The conspicuity of the crossbuck is not particularly good. The conspicuity of any highway sign comes from both the visual aspects of the sign and from its meaning to the driver (i.e., emotional or motivational content). The standard crossbuck has relatively poor conspicuity, daytime or nighttime. Some recent modifications (e.g., the Ohio Buckeye device) have sought to improve this poor conspicuity by improving reflectorization, adding a red border, and adding a Yield panel. A Yield sign or panel would add to the visual conspicuity aspects. The sign or panel might also enhance conspicuity because

TABLE 3 Promising TCD summary

Element	Application	Need Addressed (Information Need, Driver Knowledge)	Design Issues
Yield sign (red-and-white triangle, as in R1-2)	Locate at crossing as the basic TCD	• Presence of crossing ahead (additional sign and retroreflective surface area, sign with salience to drivers) • Crossing type • Driver responsibility (and related need to slow and search) • Greater uniformity/ predictability of actions of other traffic	• Stand-alone or mounted with crossbuck; addition of To Trains or other messages; location • Indication of proper stopping point • Concerns regarding Uniform Vehicle Code definition; concern of all liability on driver; need for Yield (Stop) Ahead sign • Concern regarding disrespect for Stop sign in other applications
Stop sign (R1-1)	Where conditions warrant use		
Passive and active crossing advance warning signs	Used in advance zone to designate crossing ahead as W10-1 is currently used	• Crossing type • Driver responsibility	• Best way to distinguish active from passive: two new signs, one new sign, use of current advance warning sign for only passive, supplemental plaques
Railroad crossing special requirements indication	Used in advance zone in conjunction with advance warning sign for those sites with limitations of any sort (e.g., sight distances, skewed crossings, rough crossings, etc.)	• Enhance risk perception (presence of limitations ahead) • Presence of crossing ahead • Awareness of specific limitations and driver requirements	• Set of site limitations/ driver needs and related signs; placement of signs; warrants for using Stop sign control, rather than signing for deficiencies • Effectiveness of indicating a rail crossing hazard zone vs. just signing for the specific limitations • If indicating a zone, best way to indicate entry into zone

the Yield message is more urgent because of its association with other traffic applications.

4. Compliance is difficult to measure for either crossbucks or Yield signs because the overt vehicle-control response is not well defined. However, it is felt that compliance with or respect for crossbucks is low relative to intersection-type TCDs.

For all of these reasons, it was felt that a Yield sign or a conspicuous Yield message would be an improvement over the crossbuck-only treatment. The crossing would be more evident to the driver, the absence of active warning would be more evident, the appropriate action would be clearer, compliance would be greater, and traffic actions would be more predictable. What was not clear from the literature, as well as from various implementation and liability issues, was how best to incorporate the Yield message at the crossing. Should it be in the form of a standard Yield sign (i.e., R1-2)? If so, should it be used in conjunction with or in place of the crossbuck? If used with the crossbuck, should the two devices be comounted or separately located? Must the message be altered (e.g., add a To Trains line to the Yield sign wording) for either clarity or legal reasons? Thus, although the use of a Yield sign or message was suggested as the standard treatment for a passive rail-highway grade crossing, a host of specific design and implementation questions had to be deferred.

2.3.2.2 Stop Sign

The literature review and analysis did not suggest that a Stop sign was the optimal device as the standard treatment for passive crossings. However, there are certain conditions in which a Stop sign may be preferred in place of a Yield sign. A primary consideration is where there is limited corner sight distance such that the driver will not be able to see an oncoming train sufficiently far in advance to be able to come to a stop before the crossing. In this case, a Stop sign may be more appropriate because it requires the driver to come to a stop (or at least significantly reduce speed) so that a view of the oncoming train can be made safely. Other conditions that may warrant the use of a Stop sign include the presence and severity of additional crossing features such as a humped or rough crossing or high-speed passenger trains.

The general argument for using a Stop sign in place of a crossbuck-only treatment at the point of the crossing is similar to the argument made above for the Yield sign. However, there are other concerns with the Stop sign that suggest its use be limited to only selected warranting conditions. These considerations included the following.

1. Studies have consistently observed low rates of compliance with Stop signs that are used at rail crossings even though their use is typically limited to more severe sites. There is concern that broad use at passive crossings would further reduce the perceived urgency and legitimacy of the Stop message, degrading compliance further.
2. Concern has been expressed by the traffic engineering community that the widespread use of nonrequired Stop signs will breed a general disrespect for this TCD that will generalize to other applications. There is no direct empirical support for this breeding of disrespect, and, in fact, it would be very hard to prove or disprove. However, because Stop signs are so widespread and critical in intersection traffic control, there is a potential for severe consequences even if there is only a minor amount of generalized disrespect.
3. Many passive crossings simply do not require a stop on the part of the driver. There is no reason to impose this level of control.
4. Stop signs have the potential to increase substantially the number of vehicle-vehicle collisions at the crossing. Direct data are lacking, but there are substantially more nontrain collisions at crossings than there are vehicle-train collisions (*22*). Industries in which vehicles have special stopping requirements (e.g., buses, hazmat) have expressed complaints about the number of vehicle-vehicle crashes they suffer at crossings; however, it is not evident to what extent these crashes are due to a stopping requirement, per se, and to what extent they are due to the industries having a requirement different from the stopping requirements of other traffic.
5. If Stop sign use were widespread, the effectiveness of other passive control devices at crossings (i.e., crossbuck or Yield) might likely suffer because they may lack credibility.

For these reasons, the Yield sign or message is suggested as the most promising TCD for general use at the crossing, but the Stop sign is seen as a important alternative at a minority of sites at which specific conditions warrant its use.

2.3.2.3 Distinct Passive and Active Advance Warning Signs

Active and passive crossings require different appropriate actions on the part of the driver as he or she approaches and negotiates a crossing. It has been pointed out repeatedly in the literature that the standard railroad advance warning sign (i.e., W10-1) does not distinguish between active and passive crossings, and so it cannot appropriately direct the driver. Foreign practice typically distinguishes active and passive crossings in advance signage, but no evidence was available regarding the extent to which this influences crashes or driver behavior. However, the deficiency of information is clear. Furthermore, because the advance sign will often be encountered for *active* crossings, which do not impose a burden to slow and search for trains, if a driver does slow and search at an active crossing, the sign essentially was a “false alarm.” This “false alarm” presumably damages sign credibility for passive-crossing cases. Therefore, if there is a clearly understood, consistently signed distinction between passive and active crossings in the advance warning sign, this distinction should provide benefits in terms of

1. Heightened driver awareness that the crossing is not actively protected so that the burden of detecting trains is on the driver.
2. Improved credibility for the advance warning sign.
3. Earlier driver awareness that the crossing is not actively protected than if the information came solely from a Yield or Stop sign located at the crossing.
4. Improved sign effectiveness resulting in the distinct advance-crossing information and the Yield (or Stop) signing at the crossing being mutually beneficial, with one TCD enhancing the effectiveness of the other.

As with the other promising TCDs, the concept of distinct active and passive advance crossing signs was put forward without a specific recommendation regarding the precise design of these signs. There was no clear alternative based on the literature. Some have suggested retaining the W10-1 sign for one application (i.e., either for active or passive) and using a new sign design for the other. Others have suggested new signs for each application with the sign image clearly conveying the type of crossing protection for each case. It was not apparent whether it would be best to replace the W10-1 signs with new signs or to use the new signs as supplemental plates to the W10-1 sign. The most effective, best-understood graphic image likewise was not known.

2.3.2.4 Railroad Crossing Special Requirements Indication

Passive crossings can differ widely in terms of the requirements they place on the driver. Some crossings have features that require additional care on the driver's part—for example, these crossings might include limited sight distance to the crossing, along the tracks at different points along the approach, or both; a skewed-angle crossing, which can affect the sight distance; a crossing with a rough surface or a so-called "hump crossing"; or a crossing that has high-speed trains. Often the potentially hazardous feature may not be evident to the driver, which could lead to inappropriate search or overly severe vehicle-control actions such as sharp deceleration. The behavioral analysis highlighted the need for drivers to have such information in order to perform ideally. Two related concepts for indicating special requirements were considered in the preliminary recommendations. The first concept is to indicate what the limitation, hazard, or special requirement is through specific warning signs and sign-placement criteria. The second concept goes beyond the first to suggest that at crossings where there are special driver requirements, the approach zone be enhanced to alert the driver that the crossing has special requirements. The benefits of these enhancements are more speculative—it is not known to what extent the enhancements might bring improvement in driver behavior beyond that which might be expected based on the warning signs alone; these enhancements would also require more TCDs and, hence, greater cost. The general argument is to create a sign system that parallels that of a construction work zone, where advance signing and delineation are intended to alert the driver in advance and modify traffic actions through a defined zone rather than at a particular point. A variety of options are possible for an enhanced approach zone, such as modifying the standard approach sign, adding supplemental plaques, posting striped delineators on the mounting post for advance signing on both sides of the roadway, and so forth.

2.3.2.5 Summary of Promising TCDs

In summary, several types of TCDs were seen as promising for improving driver behavior and reducing crashes at rail-highway grade crossings. These devices were seen as complementary and would work well when viewed as a system of signage for crossings. A Yield sign or other Yield message display were seen as potentially significant improvements to a crossbuck-only installation. The Stop sign was also viewed as a promising alternative to the crossbuck-only treatment, but only as a treatment used under warranted conditions. The approach to the crossing would benefit from an improvement to the current railroad advance warning sign so that the driver understands on approach that there is no active warning at the crossing ahead. Crossings that impose special requirements on the driver are also indicated by advance warning devices. Taken together, this collection of promising TCDs addresses the most prominent deficiencies in current practice. However, the optimal designs or criteria for implementing any of these TCDs were not known. Also lacking are credible data on the ultimate safety benefits.

2.3.3 Preliminary Evaluation of Device Effectiveness and Costs

Having defined the promising TCD measures and their rationale, the research team's next effort was to assess the TCDs' effect on driver behavior and crashes and to estimate their life-cycle costs. These issues are addressed in the following sections. It should be understood that there is a lack of empirical findings from which to project the behavioral or crash reduction effects of alternative TCD systems.

2.3.3.1 Effect on Driver Behavior

Of the several promising TCDs, reasonable information on the behavioral effects is available for only one of them—the Stop sign. There is relatively little information on the behavioral effects of Yield signs at rail-highway grade crossings or of distinct advance warning signs and hazard warnings. One behavioral aspect all of these devices are likely to share is the effect of repeated experience. The majority of traffic using a particular crossing tends to be familiar drivers who encounter the site frequently; this is probably particularly true for passive crossings, which are more likely to be on low-volume roads. TCDs are most likely to be noticed and responded to by unfamiliar drivers. Drivers repeatedly encountering a given crossing will come to pay less attention to the signs. However, this does not necessarily mean that a given TCD does not have a long-term effect on driver behavior because it may help initiate and maintain appropriate driver actions (e.g., search, speed choice) even if those actions are no longer the immediate result of looking at the sign.

With regard to Stop signs, there is good evidence of likely driver behavior. Several studies report a high level of noncompliance as measured by the lack of complete stopping. A high level of noncompliance was even found at crossings with limited sight distance. However, there is a high percentage of drivers who nearly stop or at least reduce speed. There are also some indications of better visual search. From these studies, one may assume that considerable noncompliance will continue with the use of Stop signs. Furthermore, it can be hypothesized that the level of noncompliance will increase over time at a specific crossing (because of frequent users becoming less concerned). There are not good data on the generalization of noncompliance to other Stop sign applications. Concern exists that if the use of Stop signs becomes widespread at crossings, without regard to specific and limited warrants, there will be heightened disrespect for this TCD; therefore, the effectiveness of the Stop sign will be dependent upon its selective use and the need for education and enforcement. Another behavioral aspect of the Stop sign is its influence on vehicle-to-vehicle interactions. This consideration has been absent in research studies even though there are more nontrain crashes at crossings than there are vehicle-train crashes (*22*). Because a wide range of responses to the Stop sign at crossings is seen—from not even slowing to complete stopping—it seems likely that there will be more speed variance at the crossing and more vehicle-following problems.

As reported in the literature review findings, Yield signs for grade crossings have not had a comprehensive evaluation; hence, there is no substantive evidence of how they may affect driver behavior in the near or long term. Studies that have been done involving the Yield sign or the Yield message included within the crossbuck are limited and somewhat flawed. However, the studies do indicate that the Yield sign conveys the message that the driver has the responsibility to look for and yield to an oncoming train better than does the crossbuck sign alone. It is expected that this knowledge should increase advanced searching, but how this apparent effectiveness carries over to actual locations, especially if most passive crossings were to have a Yield sign, is a matter of conjecture. According to the Uniform Vehicle Code, the driver of a vehicle approaching a Yield sign shall slow down to a speed reasonable for the existing conditions and, if required for safety, stop to yield to a vehicle that is in the intersection or approaching on another roadway. When used at a crossing, one would expect to see a level of observance ranging from no speed reduction—at crossings with long—sight distance triangles and smooth crossings—to varying levels of speed reduction. This behavior will likely vary by driver familiarity of the crossing. The driving population that crosses the tracks on a frequent basis eventually is likely to revert back to its behavior before the Yield sign was installed. Those drivers who are crossing the tracks for the first time or very infrequently, however, would be more prone to respond by slowing somewhat and would be more conscientious about searching for an oncoming train.

No information exists on the behavioral effects of using distinct advance warning signs for passive and active crossings. The behavioral benefits of such a sign would be related to the simultaneous use of the Yield sign or message. If the sign message conveys a clear sense of the absence of active protection and the driver requirement to look for trains, then the sign may be expected to increase search behavior, at least among those less familiar with the crossing. The presence of the Yield sign enhances this message. Likewise, if the driver knows in advance that the crossing does not have gates, bells, or any other train-activated device, then the Yield sign will have more significance. The driver will better understand what is expected, and the behavior in terms of looking for trains and adapting speed is likely to improve.

The final set of TCDs considered are those related to the presence of specific features at a particular crossing that require additional attention on the part of the driver. One aspect of this recommendation is to provide specific advance warning signs or supplementary panels to indicate the specific hazards or behavioral requirements associated with a site. An additional possibility is also to provide some form of enhanced advance signing or delineation, prior to encountering the hazard-specific sign or signs, to indicate that there is some exceptional requirement at this crossing. The purpose of the specific warning messages is to promote appropriate behaviors, and the purpose of the enhanced indication of a crossing zone when there are limitations is to improve the response to those signs. The assumed benefits of the hazard-specific signing on driver behavior are based on the argument that the driver cannot appropriately adjust speed and search if the demands of the crossing are not evident or conspicuous sufficiently in advance. As to treating crossings with unusual demands as a “zone,” although there are no data to indicate the behavioral effects of such a sign, the concept may be viewed as analogous to advance warning signs for construction and work-zone areas. Research on work-zone safety has suggested the importance of enhanced advance signing, which alerts the driver to the need for heightened attention and increases the readiness to respond to subsequent more-specific signage. Various potential hazards at a crossing cannot be responded to in advance because they may not be very evident at a distance (e.g., limitations to visibility along the track at the crossing or a hump crossing). The work-zone experience suggests such TCDs can promote desired behaviors (e.g., slowing, searching, general caution), but there is no direct evidence regarding the expected behavior actions for the railroad-crossing application.

2.3.3.2 Potential Effect on Crashes

The literature review found little empirical basis regarding the change in crash rates at crossings with either a Yield or Stop sign. There are very few locations with a Yield sign or a Yield message included with the crossbuck, so no study has been conducted of the crash effect when Yield signs are used. There have been evaluations regarding Stop signs, but these have not been definitive. Furthermore, the findings are undoubtedly related to the nature of the sites chosen for application of Stop control—for example, Sanders et al. (*10*) analyzed crash data in an attempt to establish whether crossings with Stop signs and crossbucks were safer than crossings with crossbucks alone. Their analysis, which was hampered by lack of exposure data, indicated that locations with Stop signs had a slightly higher crash rate than those locations with crossbucks alone. This does not mean, however, that the installation of Stop signs will cause an increase in crashes at the crossings. If Stop signs for passive crossings are used for those crossings that are deemed hazardous, then a higher crash rate can be expected. What needs to be established is how the crash experience might change with the installation of Stop signs at crossings where there was only a crossbuck or even a Yield sign; this finding will be related to the criteria used for selecting appropriate sites.

2.3.3.3 Initial and Maintenance Costs

In this task, the life-cycle costs associated with promising devices were also to be determined. The devices being suggested as "promising devices" are relatively inexpensive; however, when applied to a large number of crossings, the devices can represent a significant cost to the responsible agency. The cost of an installed sign of the type being suggested (i.e., a Yield sign, Stop sign, or advance warning sign) can range from $100 to $150 depending mostly on the labor and equipment costs and on how many signs are being installed. Assuming that two new signs—an enhanced railroad advance warning sign (i.e., W10-1) and a Yield or Stop sign—would be installed, the costs for these signs are estimated as follows: for the sign assemblies, $125 each ($500 per crossing); for dispatching the installation crew, $100 per crossing; and for actual installation, $50 per sign assembly ($200 per crossing). These costs total $800 per crossing. Based on FRA's National Highway-Rail Crossing Inventory database, there are about 71,000 at-grade crossings that currently do not have either active control devices or in-place Stop signs. If all these crossings were changed, the national cost for initial implementation would be about $57 million.

In addition to the installation costs, many of the crossings will require some engineering analysis to determine whether a Yield or Stop is most appropriate. The cost of this analysis is estimated at $1,500, about 1 person-week, divided among licensed engineers, technicians, sign management, and supervisory work. We estimate that 20 percent of the crossings will require analysis, resulting in a total cost of $21.38 million.

After installation, a sign generally does not require routine maintenance. Replacements during the normal service life are typically needed because of vandalism or accident. Among a large group of signs, the loss rate is expected to be around 1 percent. The estimated cost of replacing an individual sign is $270. This higher unit cost reflects the fact that replacement signs must be installed individually rather than as group, as is the case with the initial installation. The annual cost for these replacements is about $1.15 million.

2.4 DRIVER FOCUS GROUPS

Two driver focus groups were conducted to better understand driver beliefs, perceptions, and expectancies regarding passive rail-highway grade crossings and associated TCDs. Of particular interest was how drivers would interpret various types of information in the context of these crossings and in perceptions of TCD concepts or elements raised in the preceding tasks. As a qualitative technique, the focus group method was not intended as a means of acquiring quantitative data on driver response or preference. Rather, the interest was in how people view different sign aspects or configurations, problems of interpretation and sources of confusion, current misbeliefs that need to be overcome, and the implications drawn from a message.

2.4.1 Focus Group Method

Two focus groups were conducted, each composed of ordinary local drivers who reported driving at least 3 to 4 days per week. They were paid for participation and recruited through local advertising. No mention of railroad crossings was made during recruitment and screening of participants; the request was for ordinary drivers sought for a discussion group on highway signs and markings. One group was held in Rockville, Maryland, a suburb of Washington, D.C. (11 participants); the other was in Hagerstown, Maryland (12 participants). The two areas differed substantially in both demographics and rail operations. The Rockville group was ethnically diverse and ranged in age from 22 to 77. Some had past experience driving commercial vehicles or school buses. The group was drawn from a suburban region that has relatively few at-grade crossings; almost all of the crossings had active TCDs.

The Hagerstown group was composed of individuals ranging in age from 22 to 70 and was drawn from Maryland's Washington County region. Two participants had extensive experience driving commercial vehicles, particularly heavy trucks. Relative to the suburban Rockville area, the Hagerstown area is much more rural and blue collar and less ethnically diverse. There is considerable rail activity from multiple rail lines, including a number of passive grade crossings.

Each focus group took about 2 h and followed a carefully structured question path. After self-introductions, the session began with an "ice breaker" question. Each person was given a transparency sheet that had a plan-view diagram of a two-lane roadway with a railroad track crossing it. The person was asked to draw in "all the signs and markings you would see on a typical railroad crossing." Some examples of plan-view diagrams with TCDs, for work-zone and bicycle lane applications, were taken from the *MUTCD* (*1*) to show the participants how to do the drawings. These *MUTCD* examples were selected because they contained a range of advance and at-site signs, roadway markings, and other types of devices and features. Participants were asked to be as specific as possible in their use of wording, graphics, and location. After the drawings were completed, several of the drawings were viewed and discussed by the group. This procedure served two functions. First, it provided potentially useful information on what people perceive current practice to be and what sorts of misconceptions are involved. Second, the procedure brought everybody into the exercise and helped foster participation and cross talk.

Following this drawing, the discussion moved to consideration of the railroad advance warning sign (i.e., W10-1). The discussion was directed to cover issues such as

- What is it for?
- What should you do when you see it?
- Where is it located?
- Is it used at every crossing?
- Does it work well (why)?
- What would make it more effective?

Following discussion of the advance sign, the discussion moved to consideration of the standard crossbuck (i.e., R15-1) for a similar set of issues. After this, the general layout of the standard TCD system at crossings was discussed.

Following the consideration of current standard devices, the discussion moved to the distinction between active and passive crossings, including viewing a variety of specific alternative advance warning sign designs that have been suggested. The discussion then moved to consideration of the Yield message at a passive crossings and ways that this idea might be communicated. Again, this included viewing various designs that have been suggested. Finally, there was a discussion of the entire layout of a system of TCDs for passive crossings. This discussion included consideration of signs that are sometimes used at crossing sites (e.g., skewed-crossing warning sign), the adequacy of practices, what additional information the driver would like or expect, and improved concepts.

2.4.2 Focus Group Findings

2.4.2.1 Image of Current Typical Practice

Drivers generally imagine current practice to be something quite different than it actually is. Only 1 person out of 23 came close to accurately portraying actual practice. Most drawings excluded various primary TCDs and introduced inaccurate or atypical devices. Figure 2 illustrates a typical example of these drawings.

Among the primary findings to emerge from this portion of the procedure were the following.

- Very few drivers (only 5 of 23) included a crossbuck in their drawings. This number included only a single driver from suburban Rockville. An "X" symbol was present in some other signage, but not a crossbuck, and not at the crossing. Subsequent discussion revealed a widespread belief that crossbucks were not universally used, but rather selectively placed at certain types of crossings (e.g., only in rural areas or on high-volume roads).
- The W10-1 advance warning sign was portrayed somewhat closely—a circular sign with RR and X elements, even if not placed properly—by only 5 of 23 people. Of these five, one placed it only at the crossing; two others used it both at the crossing and in advance. However, although few people portrayed a W10-1 sign, the vast majority of people (18 to 20 people, or up to 87 percent, depending on interpretation of the drawing) showed some sort of advanced warning or informational sign. Although the drawn signs were diverse and carried a number of different messages, many had some elements common to the W10-1 sign (e.g., a circular shape, X, or RR). For advance signs, the circular shape was seen in 8 drawings, the X in 9 drawings, the RR in 11 drawings, and at least one of these elements was seen in 15 of the 23 drawings

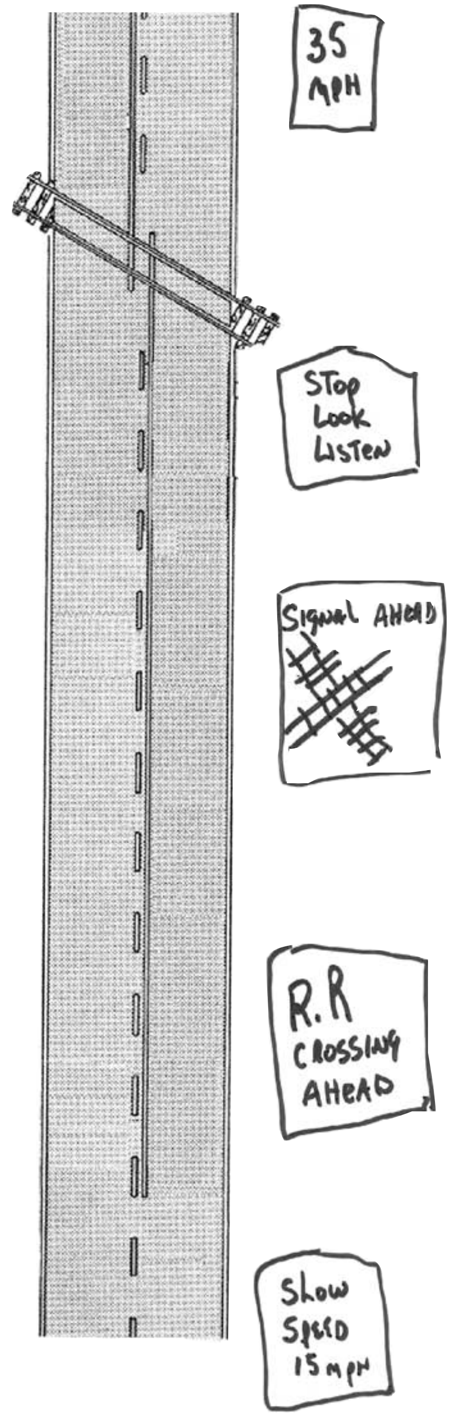

Figure 2. Example sketch.

(65 percent). Furthermore, similar signs were shown *at* the crossing, rather than in advance, for several other participants. Circular, rectangular, and diamond-shaped sign fields occurred with equal frequency.

- Only four to six people (depending on interpretation of ambiguous drawings) showed any pavement markings. Only two of these markings were even close to the "RXR" marking typically used. The others were some form of transverse marking, such as a stop line or cross-hatched area, at the crossing.
- The directions did not specify whether the crossing was active or passive, and this issue had not yet been raised for the group. More than half the drawings (13 of 23, plus 2 ambiguous drawings) portrayed some form of active TCD at the crossing. Interestingly, most people at the Hagerstown site (8 or 9 of 12) showed an active crossing. In contrast, fewer people at the Rockville site (5 or 6 of 11) suggested active devices even though the few crossings actually present in the suburban area had active TCDs. Of the Rockville drawings, only 4 of 11 actually showed an active TCD; however, 2 more indicated the presence of a device through a note or the presence of a Signal Ahead sign. Only one person explicitly indicated that there are "lights and bars" only at "some" crossings.
- Seven people (30 percent) thought some form of Stop message was typical at a crossing; this percentage is a higher frequency than the crossbuck. Because about half of all drawings showed some form of active TCD, the incidence of Stop messages at passive sites was much higher. Only one drawing showed an octagonal Stop sign. The others portrayed some message of the need to stop at the tracks, including two Stop, Look, and Listen messages and one Stop pavement marking. Six of the seven Stop message drawings were from the suburban Rockville site, which contrasts with the higher incidence of active devices in the Hagerstown drawings.
- Taking the two previous points together, it may be noted that in only 3 of the 23 drawings was there neither a Stop message nor an active TCD. In other words, almost all participants showed some "explicit" message of driver action to be taken (stop or conform with active TCD).
- In addition to general advance warning signs regarding the presence of a crossing, a few drawings (4 of 23) included more specific advisory signs with messages related to proper speed, slowing, or looking.

In summary, this portion of the procedure revealed that drivers do not have an accurate appreciation of actual TCD practice. The crossbuck, in particular, appears to be little noted or remembered, nor is it seen as universally applied. People do have a high expectation of advance warning signs even though they seldom accurately describe the current W10-1 sign. Elements of the W10-1 sign, however, were frequently shown in advance signing (65 percent had one or more elements). In the majority of cases, people portrayed either an active TCD or an indication of a requirement to stop. Drivers apparently anticipate some sort of explicit indication of the required behavior at a crossing. There is a perception that the use of the crossbuck, advance warning sign, or both, is not uniform at all crossings, but rather are appropriate to only certain applications. Also evident in the drawings, and supported in subsequent discussion, was the perception by a meaningful number of drivers that vehicles are required to stop and look at a crossing (at least a nonsignalized one) even though this action is seldom the norm.

2.4.2.2 Active and Passive Advance Warning Signs

Participants were unclear regarding the use of the W10-1 railroad advance warning sign. Many felt it was used only for selected applications such as near "major" crossings. The sign was not seen as a very effective means of influencing driver behavior. As the discussion focused more on the distinction between active and passive crossings and the related signing needs, similarities and differences between the two focus groups emerged. Both groups argued that the most desirable solution was not to discriminate between types of crossings, but rather to upgrade all crossings to active control. They felt that the public would be willing to pay for this level of protection. However, the discussions proceeded on the assumption that passive crossings will continue to exist at many locations as is currently the case. Some participants were unaware that crossings without active TCDs exist on public roads—they just assumed that if there were a significant hazard, there would be an active warning. This incorrect assumption underscored a need to ensure drivers understood the requirement to look for trains.

The rural Hagerstown and suburban Rockville groups differed in the group feeling regarding distinction between active and passive. There was good agreement among the Hagerstown participants about the great importance of providing advance signing that distinguishes between crossings that offer some form of active warning device and those that do not. Not all the drivers in the Rockville group perceived a benefit in distinguishing active from passive crossings. Some felt that doing so might complicate the situation, making it more difficult for drivers to understand their responsibilities. It is interesting to note that the group from an area with many grade crossings, including passive crossings, felt that making the active-passive distinction in advance signing was important, while the group from an area with few crossings, essentially all active crossings, had less unanimity on this point. It may be the case that drivers with little exposure to passive crossings might be the drivers that most need to be made aware of the lack of an active TCD when they do encounter such a crossing.

Both groups had individuals suggest the use of Stop signs at crossings without active devices, but there was no consensus about this. There was uncertainty in both groups as to what a driver was supposed to do at a crossing. Some believed that "stop, look, and listen" was a requirement at all crossings (or at least passive ones) even though they recognized virtually no one did this.

In discussing how to discriminate active from passive crossings, drivers in both groups emphasized that they felt it was more important for the drivers to know that a crossing was passive than to know that it was active. Because drivers' responsibilities increase at passive crossings, they must be informed of this increased responsibility. The Hagerstown group felt that advance signing should be emphatic in indicating a potential hazard; they suggested the use of words like "beware," "caution, " "danger," or "warning." The suggestion was raised in both groups that sign color be used to distinguish active from passive crossings. Other suggestions concerned using color to underscore the hazard message—for example**,** yellow signs, red text, or both, and images.

After general discussion of active and passive advance warning signs, the groups viewed a variety of suggested signs for this purpose and discussed them. The sign ideas presented to the groups are in the appendix. The groups understood that these illustrated various sign concepts and that the actual graphic images could be modified. The purpose of considering the sign set was to generate discussion of various concepts and features. The following points were among those raised in the discussion.

- There was considerable confusion and dislike for the icons used to indicate a signal light array for active crossings. Signs using this feature were not easily interpreted, and there was ambiguity about what the symbol represented and what the nature of the crossing was. Some people felt that if the symbol were comounted with the more familiar W10-1 sign, the symbol would be more likely to be interpreted by drivers. For the active-crossing message, participants in the Rockville group were enthusiastic about the use of the W10-1 sign supplemented by a panel that had a signal-light icon and the words "signal ahead." They also liked the image that paired the signal-light icon with a Train When Flashing message, although they did not like the color scheme of the example. Hagerstown participants were less enthusiastic about signs with the signal-light icon.
- Text messages were felt to make the sign's meaning clearer, but need to be used in association with other sign elements to clarify the message's relationship to the crossing—for example, Signal Ahead could refer to either a highway intersection or a railroad crossing signal light. Some expressed concern about the driver's ability to read text messages (e.g., language, vision problems, legibility) and the potential for extra burden on the driver.
- For passive crossings, participants were favorable to the idea of pairing a supplementary panel with the W10-1 sign. Many did not like the icon alone or the No Signal Ahead message unless it was clearly associated with the W10-1 sign.
- Reaction was unfavorable to the idea of using the circle-and-slash image (superimposed on an icon with a signal light) to indicate the absence of an active device. Some people expressed confusion over the meaning: Might it mean there are no trains ahead or that the crossing is closed (i.e., "do not proceed over tracks")?
- The No Bells or Lights message was felt to be very understandable if used with the W10-1 sign, but there was some concern about whether this was too much text.
- There was some feeling that the proposed concepts were not "strong enough" and that words like "danger," "warning," or "caution" should be used in conjunction with the W10-1 image or messages such as No Signal Ahead. Some participants felt that the current signs lacked "impact" for the driver and that they often drove past the advance warning sign with no awareness. They felt that emphatic keywords would make the sign more attention-getting and would more directly convey the need for the driver to be cautious.
- In the Hagerstown group, many of the participants liked the suggestion of one member that a rectangular yellow sign be used containing both a black W10-1 image and a red No Signal Ahead message.

2.4.2.3 Use of Yield Sign or Yield Message at the Crossing

After consideration of advance signing, the discussion turned to signs used at the crossing proper. The moderator explained that "when a driver comes to a railroad crossing where there are no lights or gates, he has the responsibility to look for any trains that are approaching and to give them the right of way if there is a conflict. In other words, the driver has to yield the right of way to the train." The discussion then considered the effectiveness of the crossbuck and alternative signs in conveying this concept to drivers at a railroad crossing. Example ideas were considered as shown in the appendix. (It should be noted that the illustration of the Buckeye crossbuck shows it as black and white; the actual Buckeye crossbuck is red and white.)

For both groups, there was a widespread lack of understanding of the intended message and use of the standard crossbuck. People thought the crossbuck simply marked the location of the tracks, and a few thought it meant "stop, look, and listen." Many did not believe the crossbuck was used at all crossings (including active crossings) or that it was widely used. Some thought its use was restricted to rural areas, back roads, or selected traffic characteristics. Some participants in the Rockville group seemed unable to grasp the idea that the crossbuck had a different meaning (in terms of driver requirements) at active crossings where it does not mean "yield"; this idea was not an issue for the Hagerstown group.

In both groups, there was no consensus about the desirability of including some form of Yield message in the signage at the crossing. Some favored the idea in one form or another. Others felt that it is obvious that the driver needs to yield to a train ("Wouldn't any idiot yield to an oncoming train?"). The underlying assumption, of course, is that the approaching driver needs to become aware of approaching trains in order to determine whether there is a need to yield right-of-way. Some felt, therefore, that it may be more valuable to directly instruct the driver to search for trains. Other objections to the use of the standard Yield sign included driver disrespect for the sign and difficulty enforcing the sign. Some suggested that advisory messages like Danger, Warning, Caution, or Look for Trains might be more effective. Another suggestion was for a graphic image such as a car and a train colliding. Various participants thought such messages might better communicate impending danger and the need to approach the track cautiously. The distinction between advance signage and at-the-track signage frequently blurred during these discussions.

After general discussion, the set of at-crossing TCDs shown in the appendix was reviewed, and discussion focused on how to best convey a Yield message. The following points were raised:

- The Yield sign, if used, should be presented in conjunction with the crossbuck so that the intended referent (i.e., the train) is made clear.
- The Yield sign, if used, should be presented in its entirety (including the word "yield"). Alternatives incorporating only some features (e.g., shape, color) were not as clear.
- The safety impact of the Yield sign is debatable, and some felt it was "overkill."
- People reacted negatively to images that had the crossbuck superimposed over a Yield symbol–like background field. The meaning was not immediately clear, and some felt the crossbuck appeared to be "crossing out" the Yield message or telling drivers *not* to yield.
- Some felt that adding a supplemental To Trains plate with the Yield message helped make the referent clearer, but others felt this was redundant because the track (and crossbuck, if present) made this adequately clear.
- There was a feeling that if a regulatory sign such as Yield is used at a rail-highway grade crossing, then there must also be some enforcement effort.
- Although most people appeared to favor the use of the standard red for the Yield, there were suggestions for the use of yellow (to imply caution) or lime green (for conspicuity).
- Placement of the Yield message as text on the crossbuck arms was generally not favorably viewed, having little attention-getting value or impact.

2.4.2.4 Use of Enhanced Approach Zones and Signs Denoting Unique Crossing Features

The final portion of the focus groups discussed sign "system" issues. This discussion included both the need for additional messages when there are unique features of a site and the general scheme for laying out a sequence of TCDs at typical sites. To spur discussion, example signs and layouts were considered. These examples are presented in the appendix.

There was favorable response to the idea of enhancing the approach to the crossing through the use of roadside delineators and "approach-zone" concepts. However, there was feeling that there would be a need for public education if such practices were to be adopted. If roadside delineators or distance markers are used, it was suggested that they be placed on both sides of the road.

The response to specific warning signs for various site features was mixed. Some people questioned the need to inform the driver about track geometry (e.g., oblique crossings) although others thought this information would be a useful aid to search. Opinion was also mixed on the need for a warning about high-speed trains. In general, the "view of trains limited" concept was seen as important to communicate, but the groups did not like the wordy text message. Suggested alternative wording included "hidden train," "obstructed view," or "limited view."

There was some concern expressed that enhanced approach-zone delineation or additional warnings could have the potential to escalate to a large number of visual elements, which could overwhelm drivers. Although a reasonable concern, it is ironic because many of the participants' drawings of what they considered current "typical" practice (in the initial phase of the focus group procedure) included much more information than is actually the case. Some participants also raised the question of whether enhanced treatments might result in increased costs for installation and maintenance.

In considering ideas for the general layout of TCDs for passive crossings, participants viewed and discussed the current U.S. and Australian standards (in plan views). The Australian scheme has more extensive signing and marking. Many preferred the Australian approach as more informative although others were concerned about too much information. There was positive feeling that the placement of a rumble strip just prior to the advance warning sign would alert drivers to a situation requiring caution and lower speeds. There were also suggestions, with agreement among many, for the placement of additional signs between the advance warning sign and the track. This included a Reduce Speed or Caution sign shortly after the advance warning followed by another sign that communicates the lack of an active TCD (e.g., No Signal Ahead). Most participants seemed to feel that placing signs in this manner at a passive crossing site would increase safety and communicate the intended messages to drivers. Still, the groups re-emphasized their beliefs that converting all passive crossings to active ones would be the most desired approach.

Other suggestions for improving safety at railroad crossings were solicited during this discussion. Participants thought that further education was needed among the general public to inform drivers of the responsibilities required of them at passive crossings. When asked about the usefulness of Stop signs at passive crossings, the response was mixed. Some felt that Stop signs might be appropriate in some situations, but less so in crossings with low train traffic. One participant wanted Stop signs installed so that everyone was expected to stop and other drivers would not become angry with her for stopping as she currently does at most passive crossings. Still others thought young, inexperienced drivers would benefit from being "forced" to stop at passive crossings. However, concerns about rear-end accidents and resulting traffic problems surfaced in the discussion although participants did not feel installing Stop signs at crossings would necessarily degrade respect for Stop signs in highway situations.

2.4.3 Focus Group Summary and Conclusions

The focus groups provided a number of findings concerning drivers' perceptions of rail-highway grade crossing delineation practices. The findings should be treated as qualitative and are limited by the use of only two groups. Nonetheless, various points were raised that merit consideration in the development of recommended practices. Although these issues are detailed in the discussion above, a few key findings are highlighted as follows.

- Current practice is not well understood by drivers.
- A meaningful number of drivers do not realize that passive crossings occur on public roads.
- Drivers anticipate, and want, more information than current practice provides.
- Although many participants felt the active-passive distinction was important to make for drivers, others did not grasp the significance of this difference.
- In distinguishing active from passive crossings, it is more important to drivers to be aware of when the crossing is passive.
- Some drivers believe that "stop, look, and listen" is the requirement at a passive crossing even though they acknowledge that essentially no one stops (unless a train is coming).
- There was no consensus, and there was a range of opinions, regarding both the use of Stop signs and the use of Yield messages.
- There was some preference for sign concepts that added text panels to icon signs, including the W10-1 sign.
- The use of the circle-and-slash symbol for negation (e.g., "no signals") was widely disliked and felt to be unclear.
- Many discussants favored the use of direct sign statements of what to do: Slow, Look for Trains, or Use Caution.
- There were favorable reactions to the idea of an enhanced crossing zone as long as this enhancement did not result in a visually "noisy" situation.
- There was feeling that it would be best to upgrade all crossings to some form of active control.

2.5 TCD COMPREHENSION TESTING

2.5.1 Comprehension Test Method

Using specially developed booklets, the meaning of alternative sign concepts was evaluated through comprehension and preference testing. The focus of interest was on advance railroad crossing warning signs that distinguished active and passive crossings and signs for use at passive crossings that conveyed information related to the crossings' passive nature.

Testing was done by having participants write answers to questions in answer books. The books contained sections on both comprehension (What does the sign mean?) and preference (Which alternatives for a given message are preferred, and why?). Participants were trained in small groups of up to 10 people and, with monitoring from the researcher, began filling out the books during this session. The participants then took the books home to complete them and returned them to the researchers via prepaid delivery services.

Comprehension and preference data provide useful information for comparing alternatives and refining designs based on problems, confusions, and driver opinion. However, the numbers from this sort of testing should not be taken literally as actual quantitative descriptions of real-world performance. The findings should be considered with the other sources of information and analysis used in this project.

2.5.1.1 Locations and Participants

The participants were recruited for sessions in four geographic locations: Rockville, Maryland; Madison, Wisconsin; Hagerstown, Maryland; and Columbus, Georgia. They were recruited through local advertising to take part in a study of "highway signs"; no mention of rail crossings was made. Slightly more than 100 participants were scheduled with approximately equal numbers of males and females and three age groups (16 to 25, 26 to 64, and 65 and older). Ninety of the scheduled participants showed up for their scheduled session and took part. Sixty-six of the 90 participants returned completed, usable booklets. The analyses that follow are based on these 66 participants. This group included 37 females and 29 males. There were 19 participants in the young group (17 to 25), 27 in the middle-age group (26 to 64), and 20 in the older group (65 and older). Twenty-one participants were from the

Rockville group, 15 from the Madison group, 19 from the Hagerstown group, and 11 from the Columbus group.

2.5.1.2 Signs Investigated

Twenty-eight distinct signs related to rail-highway grade crossings were included for evaluation. These are shown in Figure 3. The signs are of three types: railroad advance warning signs for passive crossing application (12 signs, including the current W10-1); railroad advance warning signs for active crossing application (7 signs, also including the current W10-1); and rail-highway crossing signs for application at passive crossings (10 signs). It should be noted that the version of the Buckeye crossbuck tested (At Crossing, Sign C in Figure 3) was inadvertently presented as black and white rather than in its actual red-and-white coloring.

This set of signs was derived based on a number of sources and considerations. Candidates were identified through existing literature, published research studies, signs that are in use or have been suggested for use, and the findings from focus groups. In addition, a request for sign ideas (either in existence or new) was widely disseminated to the expert community, through announcements and requests made through organizations including TRB, the Institute of Traffic Engineers (ITE), NCUTCD (Rail-Highway Grade Crossing Committee), AASHTO, Operation Lifesaver, the Association of American Railroads, and the American Railway Engineering and Maintenance-of-Way Association. The final set of 28 signs was not inclusive of every concept, but was selected to broadly include promising sign concepts and features. It was not possible to fully cross all feature combinations and still keep the size of the sign set reasonable, but the final set does offer the opportunity to consider a wide range of examples.

For purposes of comprehension testing, these rail crossing signs of interest were embedded in a larger set of highway signs (100 total signs, including 6 training or practice signs), which are described below.

2.5.1.3 Procedure

The participants were informed that they were taking part in "a study of how understandable various highway signs are." No specific mention of railroad grade crossing signs was made. None of the training and practice scenes included rail-crossing examples. In order to discourage participants from perceiving the study as related to rail crossings, a large and diverse set of highway signs was included in the study, the majority of which were unrelated to rail crossings. Participants took part in a 2-hr session in groups of up to 10 people. In this session, they were trained in how to answer the comprehension questions and then began working through the test booklets. It typically took approximately 4 to 5 hr to complete the booklets, so after the session, participants took the booklets home to complete. In order to return the completed booklet, each person was provided a pre-addressed, prepaid envelope for a delivery service. Participants were given partial payment at the completion of the initial session and the remainder after return of the booklet.

The test booklet was comprised of three main sections. Each section was sealed separately. The participant had to complete each section before breaking the seal to proceed to the next section. The first section was of training and practice signs for the sign-comprehension procedure (i.e., six signs). The second section presented the 94 signs in the comprehension test. Although the 6 training or practice signs were always presented in the same order, the sequence of the 94 test signs was independently randomized for each participant. The final portion of the booklet was the preference-and-opinion section. In this section, participants were shown a number of alternative signs that might be used to convey a specified message; the participants were to indicate their order of preference and additional information related to their reasons and interpretations of the images.

The comprehension portion of the procedure required participants to provide open-ended responses to indicate the meaning of a particular sign. A number of previous studies in the literature have used multiple-choice procedures, which can bias responding in a number of ways. Although open-ended responses are preferred, the method is only effective if participants are thoroughly trained to provide detailed and comprehensive answers. For this reason, the initial training portion of the procedure was quite extensive, and the experimenter monitored each person's initial responses to confirm that the participants were providing appropriate, interpretable answers.

In the comprehension portion of the booklet, two images of the sign were shown on the left page, and two questions were listed on the facing right page, as shown in Figure 4. The upper figure illustrated the sign in an appropriate highway context. For clarity, the lower picture showed a larger picture of the sign alone. The context scenes were kept simple, but appropriate to the sign. Railroad *advance* warning signs did not have the tracks visible in the scene; signs for application *at* the crossing did have a visible set of tracks. Similarly, signs for the nonrail crossing–related scenes included a variety of roadway types (e.g., two-lane undivided, four-lane divided) with various features as appropriate (e.g., curves, bridges, intersections). All of the rail crossing–related signs were shown in the context of two-lane undivided roads so that scene features were not confounded with sign alternatives. The two questions on the facing page were as follows: (1) "*Exactly* what does this sign mean to me as a driver?" and (2) "*Specifically* what action would I take when I saw this sign?" Previous research (*27*) has found that requiring a detailed answer to both of these questions results in more interpretable responses.

The initial training portion of the session emphasized the need for very detailed, explicit answers to both questions even if the meaning of the sign appeared obvious. This

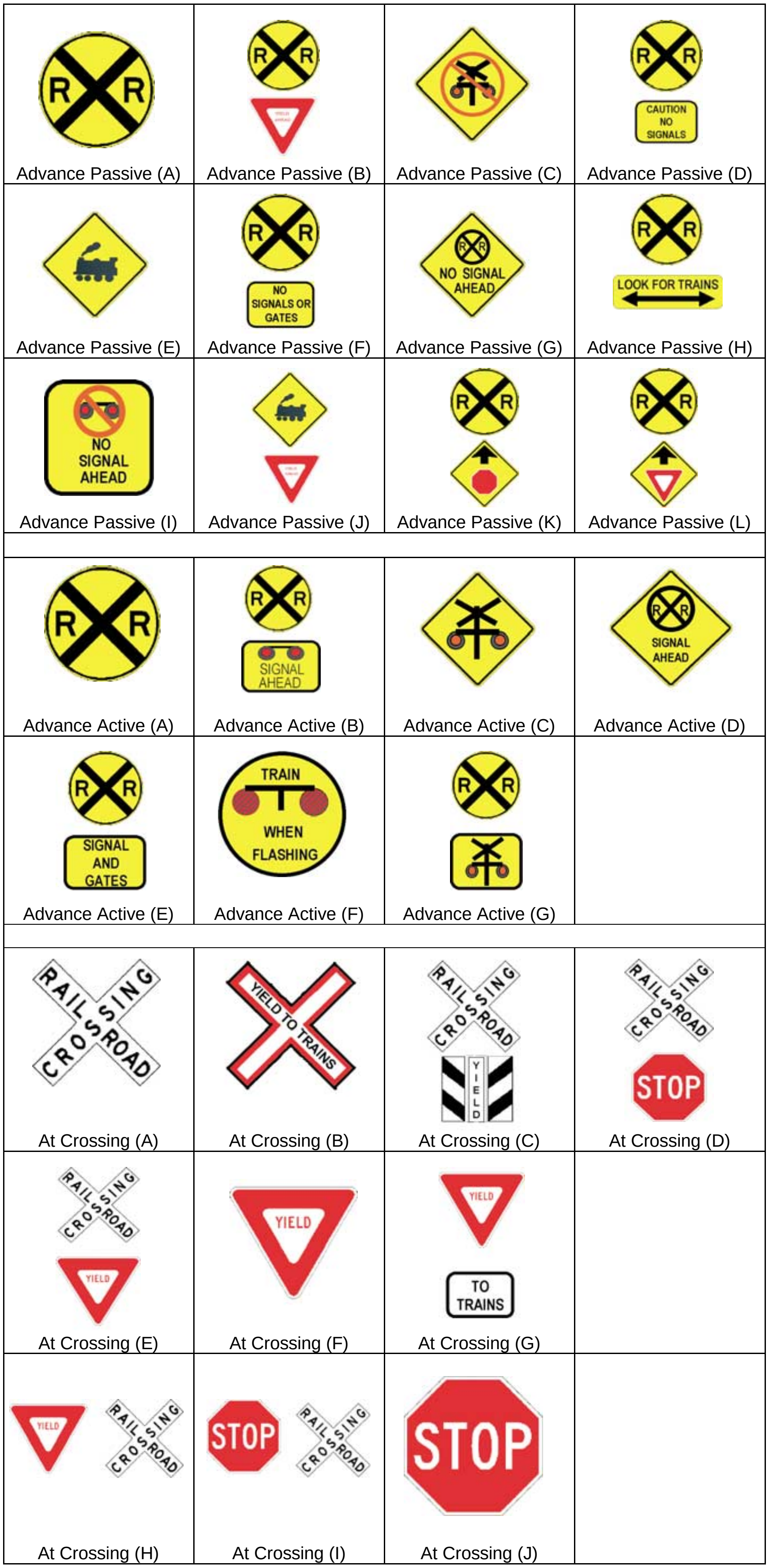

Figure 3. Signs evaluated for comprehension and preference testing.

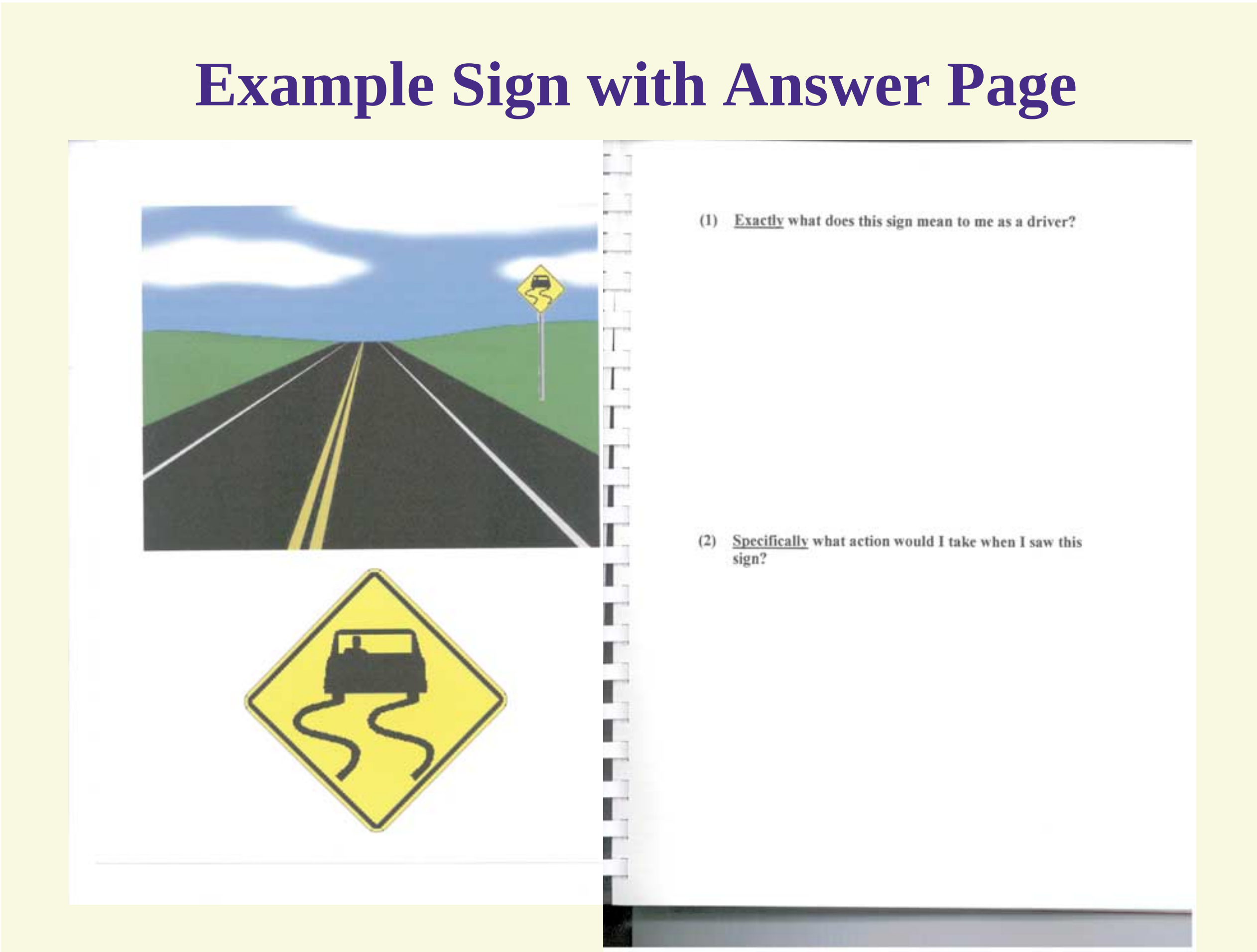

Figure 4. Booklet sample page.

emphasis included the following key statement, the gist of which was reiterated throughout training:

> Now here is a very important point I need to make. In order for us to make any use of your answers, we need you to give very detailed, thorough answers, even for simple signs like this one [the initial example sign, which was a 55-mph speed-limit sign]. We will go over some examples soon. I cannot over-emphasize the importance of detail in your answers to both questions. Do not assume that any information is general knowledge. When writing the details for each question, you may want to pretend that you are explaining the sign to someone who is just learning to drive, or to a child, or to someone from a foreign country with totally different signs. You have to be very specific and cover every detail.

Six training and practice signs were then used to illustrate this in detail. The first three signs (i.e., speed limit, No U-Turn, Farm Machinery Crossing) were answered by the experimenter, who illustrated "good" and "bad" example answers. The examples covered all relevant aspects of driver behavior and pointed out the need to describe the implications of the sign for the driver, as well as the formal meaning. After these initial examples, there were three more practice signs for which the participants wrote their answers in their answer books. The experimenter monitored the answers as the participants were working on them and then discussed in detail good and bad answers to each. It was emphasized that a "good" answer was not necessarily the correct one as long as it fully explained what the sign meant to the participant and how they would react to it. The three practice signs included a warning sign (i.e., a curve sign), a diagrammatic freeway guide sign, and a European No-Passing Zone sign. The European sign was selected as an illustration of the fact that some of the signs in the set may be novel and unfamiliar and that regardless, participants must make their best interpretation even if they are unsure of the meaning. Once the experimenter determined that everyone in the group was providing satisfactory answers and understood the procedure, the group went on to begin working on the booklets. The experimenter continued to periodically monitor each person and provide additional feedback if necessary. As the end of the 2-hr session neared, the experimenter stopped the participants and then gave instructions for completing the booklets at home and returning them to Westat via the prepaid envelopes.

The final portion of the booklet dealt with sign preference. Participants came to this section after they completed the comprehension portion. There were three separate subsections each with a similar structure: (1) Advance Warning Signs for Railroad Crossings that Do Not Have Gates or Flashing Lights to Warn when a Train Is Coming, (2) Advance Warning Signs for Railroad Crossings that Do Have Gates or Lights to Warn Drivers when a Train Is Coming, and (3) Signs Placed Right at the Crossing when There Is No Automatic Warning that a Train is Coming. Each of these sections began with a detailed description of what message the sign meant to convey. The set of alternative signs for each message was illustrated (see Figure 3). The participant ranked the signs within each set from the most preferred to the least preferred. They then answered a set of five additional questions:

1. Tell us the reasons why you preferred the alternatives you rated best.
2. Tell us the reasons why you disliked the alternatives you rated worst.
3. Tell us about any problems or likely confusions you think might occur for any of these.
4. Explain how you think the best alternatives compare with the current standard sign (Sign A).
5. Can you think of better ways of conveying the intended message? If so, please sketch them below.

2.5.1.4 Scoring of Comprehension-Test Answers

Because the responses to the comprehension test questions were open-ended, scoring methods and criteria had to be developed. For each sign related to rail-highway grade crossings, a definition of a completely correct, comprehensive answer was determined. Each potential element of an answer was explicitly characterized. Every answer was then scored on a 0-to-5 scale:

- 5 = Fully Correct,
- 4 = Mainly Correct,
- 3 = Partially Correct,
- 2 = General Crossing Indication,
- 1 = Incorrect, Ambiguous, and
- 0 = Dangerous Confusion.

A "dangerous confusion" is a misinterpretation that could directly result in the driver acting inappropriately for safety—for example, if a TCD was intended to convey the message that there was no active warning at a crossing, but the driver interpreted it to mean that there were lights and gates, it is likely that the driver would not engage in appropriate visual search.

In addition to the overall comprehension score, each participant's response was coded to indicate which elements of the answer (whether correct or incorrect) were present (e.g., tracks are ahead, gates or lights present, must stop at tracks, etc.).

2.5.2 Comprehension and Preference Findings

2.5.2.1 Findings

As a group, the tested set of rail crossing–related signs typically conveyed the intended message if not the entire desired message. Somewhat more than half (53 percent) of the answers were scored as "mainly correct" with another 28 percent being "fully correct." Only 2 percent were entirely incorrect; about 5 percent were potentially dangerous confusions of meaning. However, the distribution of these answer categories varied by the category of sign (i.e., advance passive, advance active, at crossing), as well as by the specific sign design. Specifics are discussed below.

Analyses of variance (ANOVAs) were carried out on the comprehension and preference data. Each category of sign (i.e., advance passive, advance active, at crossing) was separately analyzed. Summaries of these six ANOVAs are shown in Table 4. In the table, an asterisk indicates a factor that was significant at the $p < 0.05$ level. In all cases, comprehension or preference scores varied significantly among the signs. There was also a consistent effect of age on comprehension (the middle-age group generally scoring highest), but not of sex on comprehension. For advance warnings, there was also an effect of site on comprehension with the Georgia group scoring higher. Specific findings for each sign category are discussed further below.

TABLE 4 Summary of analyses of variance

	Sign	Age	Sex	Site	Sign–Age	Sign–Sex	Age–Sex	Sign–Site	3-Way
Comprehension									
Advance Passive	*	*		*	*		*		*
Advance Active	*	*		*					*
At Crossing	*	*							
Preference									
Advance Passive	*					*		*	
Advance Active	*								
At Crossing	*					*			

NOTE: * indicates a factor is significant at the $p<0.05$ level.

Table 5 provides a summary of the major measures of interest for each rail-highway grade crossing sign. Each sign corresponds to a column of the table, and each measure corresponds to a row of the table. Note that the W10-1 advance rail crossing warning sign appears twice in the table. Comprehension data are listed under only one column (it is arbitrary whether it is listed as "active" or "passive" for comprehension because the sign does not discriminate between these). Preference data are listed under both "active" and "passive" columns because the W10-1 sign was an option for preference in both cases.

After completing the comprehension testing portion of the booklets, the next page of the booklet that the participant came to asked the participant to indicate what he or she thought the primary purpose of the study was. Although only a minority of the signs encountered in the comprehension test was related to rail-highway crossings, we thought it likely that by the end of testing, many participants would recognize that such signs were overrepresented and perhaps the real focus of interest. There were two questions regarding this in the booklet. The first question asked: "Based on what you have seen so far, what do you think is the primary purpose of this study?" The second question asked: "Were there any types of signs that stood out to you? Explain." Only about one in four participants explicitly indicated that they thought rail-highway crossings were the purpose of the study (i.e., the first question). However, it was common for participants to have noted that rail-crossing signs were frequent (about 68 percent of participants including those who identified the purpose of the study); thus, at some point during the test, many participants may have become sensitized to rail-crossing signage, and this sensitivity may cause comprehension rates to be inflated. The randomization of the sign sequence for every participant was an attempt to minimize the bias of any such effect in discriminating between sign alternatives.

2.5.2.2 Advance Warning Signs for Passive Crossings

Ideally, an advance warning sign for a passive crossing conveys that there is a rail-highway crossing some distance ahead, the crossing has no lights or gates, the driver is responsible for detecting and yielding to trains, and the driver should be prepared or begin adjusting behavior to safely detect and yield. As a group, these signs nearly always (98 percent of answers) conveyed some general indication of a rail-highway crossing. However, in only about one in five (19 percent) was the full intended message suggested. Overall, about 76 percent of the responses indicated relatively good understanding (mainly correct or fully correct). The level of comprehension, however, varied significantly among the signs as Table 5 indicates. The mean comprehension scores for alternative advance warning signs for passive crossings ranged from a high of 4.23 (for Sign F) to a low of 3.02 (for Sign C). Post-hoc comparisons (Tukey's Honestly Significant Difference Test) (*28*) were employed to determine which signs could be statistically discriminated from one another. The findings of the post-hoc comparisons are shown in Table 6.

Consistent with these comparison tests, Table 5 shows that Signs C, E, I, and J were "well understood" ("fully" or "mainly" correct) by less than 70 percent of participants. Signs C and I also showed dramatically higher rates (20.6 percent and 12.7 percent) of dangerous confusions. In considering the performance of the set of advance passive signs, comparison should also be made with the current standard, the W10-1 sign. Because the W10-1 sign (Sign A) is used for either active or passive crossings, different scoring criteria were used in judging the correctness of answers. This sign, too, was poorly understood with a mean comprehension score of 3.42, and only about 65 percent well understood. Perhaps of most concern, there were 17.5 percent dangerous confusions—this was most often due to an assumption that the sign indicated a crossing with lights or gates.

There was also a statistically significant sign-by-age group interaction, which was primarily caused by to the fact that the older participants had particularly low comprehension of the signs using a circle and slash superimposed over an image of signal lights (i.e., Signs C and I).

Looking at the frequencies of specific elements in the answers, the alternative signs had a much lower proportion of answers that indicated there was an active warning than the W10-1 sign had. An explicit indication of the yield situation only occurred with high frequency for those signs that included a Yield icon (Signs B, J, and L). Previous research, including the focus groups done as part of this study, indicated that a substantial number of people incorrectly believe that there is a mandatory stop requirement at all tracks or at all tracks without active warnings. In fact, 24 percent of the responses to the W10-1 sign indicated this interpretation. Many of the alternative advance warning signs for passive crossings also led to high frequencies of this response. In fact, three signs that included the explicit message of No Signals (Signs D, F, and G) actually had (nonsignificantly) higher rates of the "stop for tracks" element than did the W10-1. A fourth version with this message (Sign I) did not show this high rate; the reason is not evident although it might relate to the fact that a smaller number of people understood the message well to begin with. Signs incorporating the Yield icon appeared to have lower rates of the "stop for tracks" interpretation.

Preferences for the sign alternatives paralleled the findings on comprehension. In the preference portion of the procedure, participants were first given a careful description of the intended message the signs were supposed to convey. They then rank-ordered the signs in order of preference for conveying that message to drivers. Participants most preferred the W10-1 sign when used in conjunction with supplementary text panels (Signs D, F, and H). They did not like the W10-1 sign alone (Sign A), and this feeling was more pronounced for females. Participants also did not like the use of the train icon or the circle and slash (Signs C, E, I, and J).

Reasons for preference or dislike of various alternatives were examined. The most frequent reasons for preferring the

TABLE 5 Comprehension and preference measures for each sign evaluated

	Advance Signs For Passive Crossings											
	Advance Passive (A)	Advance Passive (B)	Advance Passive (C)	Advance Passive (D)	Advance Passive (E)	Advance Passive (F)	Advance Passive (G)	Advance Passive (H)	Advance Passive (I)	Advance Passive (J)	Advance Passive (K)	Advance Passive (L)
Mean Comprehension Scores												
Overall	(3.42)	3.64	3.02	4.11	3.17	4.23	3.97	3.86	3.33	3.29	3.77	3.50
Age												
Young		3.41	4.12	4.06	2.59	4.24	3.76	3.70	3.47	3.24	3.41	3.29
Middle		3.77	3.04	4.19	3.65	4.42	4.27	4.00	4.38	3.62	4.04	3.96
Old		3.60	2.30	4.00	3.30	3.95	3.70	3.76	1.95	3.20	3.65	3.00
Gender												
Male		3.70	3.07	3.96	3.26	4.19	3.89	3.75	3.52	3.37	3.89	3.41
Female		3.56	3.11	4.19	3.25	4.25	4.00	3.93	3.25	3.39	3.64	3.53
Location												
Columbus, Georgia		4.10	3.50	4.90	3.20	4.90	4.50	4.30	4.50	3.60	4.00	4.00
Hagerstown, Maryland		3.74	2.74	4.00	3.53	4.05	3.89	3.83	3.21	3.47	4.00	3.58
Rockville, Maryland		3.42	2.63	3.95	3.00	3.95	3.84	3.64	2.95	3.53	3.42	3.11
Madison, Wisconsin		3.40	3.87	3.87	3.27	4.33	3.80	3.67	3.33	2.93	3.67	3.47
Percent Dangerous Confusion		0.0	20.6	3.2	7.9	0.0	6.3	0.0	12.7	3.2	3.2	1.6
Percent Indicating That Sign Meant												
Active Warning		3.0	7.6	9.1	10.6	3.0	4.5	3.0	6.1	3.0	6.1	3.0
No Warning		15.2	68.2	84.8	10.6	83.3	84.8	19.7	78.8	7.6	9.1	6.1
Some Behavior Req.		93.9	69.7	95.5	86.4	93.9	89.4	78.8	78.8	81.8	86.4	89.4
Yield		80.3	7.6	10.6	4.5	10.6	7.6	10.6	9.1	78.8	6.1	83.3
Stop for tracks		16.7	22.7	27.3	6.1	37.9	27.3	15.2	10.6	12.1	84.8	15.2
Stop if train		27.3	10.6	19.7	24.2	19.7	12.1	15.2	19.7	27.3	7.6	18.2
Stop if signal/gate		1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean Preference Rankings												
Overall	8.06	5.82	8.58	3.60	10.38	3.05	5.49	4.62	7.40	8.31	5.23	6.55
Age												
Young	8.76	6.41	8.71	4.00	10.06	3.18	5.41	3.82	7.88	8.00	5.29	6.24
Middle	8.00	6.04	8.80	3.72	11.00	3.32	5.80	4.40	7.08	8.36	4.80	6.64
Old	8.00	5.35	8.00	3.10	9.70	2.50	5.20	5.40	7.20	8.20	5.55	6.90
Gender												
Male	6.63	5.67	7.70	3.85	9.81	3.33	5.59	4.89	7.33	8.26	5.70	7.04
Female	9.43	6.11	9.14	3.40	10.71	2.77	5.43	4.31	7.34	8.17	4.89	6.29
Location												
Columbus, Georgia	8.30	5.70	8.80	5.50	10.00	4.90	8.70	4.00	6.70	7.00	3.50	4.90
Hagerstown, Maryland	8.11	7.06	6.44	2.94	10.44	2.78	4.83	3.33	6.39	8.89	5.94	7.61
Rockville, Maryland	8.11	5.11	9.63	2.95	10.32	2.37	5.22	5.95	7.63	8.53	5.37	6.79
Madison, Wisconsin	8.40	5.73	9.40	3.93	10.40	2.87	4.53	4.67	8.53	7.80	5.40	6.33

(*continued on next page*)

TABLE 5 (*Continued*)

Advance Signs For Active Crossings							
	Advance Active (A)  	Advance Active (B)  	Advance Active (C) 	Advance Active (D)  	Advance Active (E)  	Advance Active (F)  	Advance Active (G) 
Mean Comprehension Scores							
Overall	3.42	4.55	3.98	4.20	4.39	4.62	4.48
Age							
Young	3.82	4.35	4.29	4.12	4.41	4.59	4.71
Middle	3.12	4.85	4.54	4.23	4.42	4.77	4.81
Old	3.30	4.30	3.60	4.25	4.40	4.45	4.10
Gender							
Male	3.52	4.37	3.81	4.04	4.37	4.59	4.59
Female	3.25	4.67	4.44	4.33	4.44	4.64	4.53
Location							
Columbus, Georgia	4.90	4.80	4.20	4.40	4.90	4.90	4.90
Hagerstown, Maryland	3.47	4.32	3.89	3.95	4.37	4.47	4.26
Rockville, Maryland	2.63	4.58	4.05	4.47	4.26	4.68	4.58
Madison, Wisconsin	3.13	4.60	4.67	4.07	4.33	4.53	4.67
Percent Dangerous Confusion	17.5	1.6	4.8	3.2	3.2	1.6	1.6
Percent Indicating That Sign Meant							
Active Warning	21.2	93.9	80.3	78.8	93.9	95.5	92.4
No Warning	18.2	1.5	6.1	6.1	3.0	1.5	3.0
Some Behavior Req.	89.4	74.2	77.3	87.9	83.3	66.7	89.4
Yield	10.6	6.1	4.5	9.1	9.1	6.1	7.6
Stop for tracks	24.2	3.0	7.6	7.6	7.6	1.5	6.1
Stop if train	22.7	4.5	6.1	7.6	3.0	4.5	1.5
Stop if signal/gate	1.5	54.5	43.9	33.3	54.5	65.2	56.1
Mean Preference Rankings							
Overall	5.55	1.91	5.26	4.05	2.63	4.55	3.77
Age							
Young	5.47	2.06	4.76	4.00	2.94	4.41	4.35
Middle	6.00	1.52	5.20	4.20	2.68	5.04	3.36
Old	5.55	2.05	5.55	4.10	2.35	4.10	3.40
Gender							
Male	5.56	2.00	5.04	4.00	2.74	4.81	3.19
Female	5.83	1.71	5.31	4.20	2.57	4.37	4.00
Location							
Columbus, Georgia	6.10	1.60	4.70	5.10	3.80	3.80	2.90
Hagerstown, Maryland	55.56	1.78	5.28	4.00	2.44	4.83	3.11
Rockville, Maryland	5.37	2.00	5.58	3.68	2.53	4.63	4.21
Madison, Wisconsin	6.07	1.87	4.93	4.13	2.27	4.67	4.07

(*continued on next page*)

TABLE 5 (*Continued*)

Signs At Crossings										
	At Crossing (A) 	At Crossing (B) 	At Crossing (C) 	At Crossing (D) 	At Crossing (E) 	At Crossing (F) 	At Crossing (G) 	At Crossing (H) 	At Crossing (I) 	At Crossing (J) 
Mean Comprehension Scores										
Overall	4.21	3.97	3.83	3.91	4.00	3.06	3.86	3.94	3.85	2.91
Age										
Young	4.12	3.88	3.76	3.65	4.00	2.94	3.65	3.47	3.53	3.06
Middle	4.35	4.12	4.12	4.04	4.12	3.42	3.88	4.15	4.00	2.92
Old	4.15	3.85	3.50	3.95	3.85	2.75	4.00	4.05	3.90	2.79
Gender										
Male	4.22	4.00	3.70	3.88	3.81	3.19	3.85	3.93	3.85	2.81
Female	4.22	3.94	3.92	3.92	4.14	3.00	3.86	3.94	3.83	3.00
Location										
Columbus, Georgia	4.00	4.00	4.00	4.00	4.00	2.80	4.00	4.10	3.90	2.70
Hagerstown, Maryland	4.37	3.89	3.74	3.89	4.05	3.16	4.05	4.26	4.05	2.72
Rockville, Maryland	4.16	3.89	3.79	3.89	3.74	3.26	3.58	3.68	3.68	3.11
Madison, Wisconsin	4.27	4.13	3.87	3.87	4.27	2.93	3.87	3.73	3.73	3.07
Percent Dangerous Confusion	1.6	4.8	3.2	1.6	0.0	11.1	1.6	3.2	1.6	12.9
Percent Indicating That Sign Meant										
Active Warning	4.5	3.0	1.5	1.5	0.0	4.5	0.0	4.5	4.5	0.0
No Warning	25.8	24.2	9.1	15.2	18.2	10.6	12.1	16.7	10.6	4.5
Some Behavior Req.	97.0	92.4	93.9	87.9	86.4	77.3	87.9	88.9	89.4	74.2
Yield	15.2	71.2	77.3	7.6	78.8	74.2	74.2	72.7	7.6	1.5
Stop for tracks	31.8	21.2	17.9	98.5	16.7	6.1	13.6	25.8	100.0	100.0
Stop if train	21.2	36.4	31.3	1.5	31.8	22.7	37.9	31.8	0.0	0.0
Stop if signal/gate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean Preference Rankings										
Overall	6.68	6.20	5.65	2.62	3.25	7.88	4.43	4.51	3.28	
Age										
Young	7.59	5.94	5.64	2.88	3.59	7.35	3.82	4.35	3.82	
Middle	6.56	6.48	6.16	2.24	3.16	8.20	4.80	4.56	2.84	
Old	6.05	6.00	5.20	2.70	3.00	7.85	4.75	4.50	3.25	
Gender										
Male	5.33	6.00	5.19	3.04	3.15	7.74	4.70	4.59	4.00	
Female	7.71	6.31	6.11	2.20	3.29	7.94	4.37	4.40	2.66	
Location										
Columbus, Georgia	7.50	6.10	5.60	2.20	3.80	8.40	5.10	4.40	1.90	
Hagerstown, Maryland	6.50	5.89	5.61	2.44	3.28	7.78	4.22	4.28	3.11	
Rockville, Maryland	6.26	6.89	6.00	2.00	3.68	7.79	5.00	4.58	3.11	
Madison, Wisconsin	6.87	5.67	5.53	3.67	2.60	7.67	3.87	4.67	4.47	

TABLE 6 Advance passive crossing signs that can be statistically discriminated from one another

Sign	F	D	G	H	K	B	L	J	I	E	C
F											
D											
G											
H											
K											
B											
L	*										
J	*	*									
I	*	*									
E	*	*	*								
C	*	*	*	*	*						

NOTE: * indicates a statistically significant difference.

two most-preferred signs (Signs F and D) were similar: the text and image were understandable, the sign was informative and instructive, and it gave warning. The next most-preferred sign (Sign H) had the most frequently cited reason as that it was informative and instructive. The standard W10-1 sign (Sign A) was seen negatively because it provided too little information, did not give warning, and was not informative or instructive. The remaining least-preferred signs (Signs E, C, J, and I) were all criticized for having an unclear or confusing image. The train icon sign (Sign E) was also seen as not giving warning, providing too little information, and not able to be quickly understood. Sign C was also felt not to be quickly understood. Sign I was frequently cited as having text that was unclear or confusing.

In summary, the current standard W10-1 advance warning sign is not particularly well understood, leads to a high rate of potentially dangerous misinterpretations, and is not seen as effective in terms of relative preference. It was seen as not giving adequate warning, information, or instruction. On the other hand, the standard sign conveys to almost everyone the concept of something related to a rail-highway crossing. Sign alternatives for which a word or regulatory-sign-ahead supplementary panel was added to the W10-1 sign (Signs B, D, F, G, H, K, and L) were the best understood and most preferred. The word panel versions were most preferred. They also had the highest figures for comprehension although they were not statistically discriminable from the nonword versions. The reasons for preference for these alternatives were that they were more informative and instructive and provided warning while still having understandable images and text.

2.5.2.3 Advance Warning Signs for Active Crossings

Ideally, an advance warning sign for an active crossing conveys that there is a rail-highway crossing ahead, that it has some indication (e.g., lights, gates) when a train is in proximity, and that the driver should watch for signals or gates and be prepared to stop if they activate. Alternatives to the W10-1 sign conveyed this message to the participant more than half the time, and about 86 percent of responses could be called "well understood" ("fully" or "mainly correct"). Less than 1 percent failed to understand some general connection with a rail-highway crossing. The comprehension scores for alternatives to the W10-1 sign (Signs B, C, D, E, F, and G) ranged from 3.98 to 4.62. None of these scores were statistically discriminable from one another, and all were significantly higher than the comprehension score for the W10-1 sign (i.e., 3.42). The proportion of "well understood" answers was higher for Signs B, E, F, and G than it was for the two signs that used a diamond-shaped field (Signs C and D). Of particular note is that none of the alternatives had the high rates of critical confusions associated with the W10-1 sign. Although the worst case (Sign C) had a critical confusion rate (4.8 percent) that was about three times higher than the rates of the best cases (Signs F and G), these rates were not statistically distinguishable.

Looking at the frequencies of specific elements in the answers, Signs B, E, F, and G more often contained an indication of some active warning than did Signs C and D. In fact, about 6 percent of answers for Signs C and D indicated there was no active warning although this could not be statistically discriminated from the lower rates for Signs B, E, F, and G. Signs C and D also had a lower proportion of answers explicitly indicating the need to stop if there is a signal or gate. In general, then, there appears to be better understanding for the three signs incorporating the W10-1 sign with supplemental plates (Signs B, E, and G) and the circular Train when Flashing sign (Sign F) than for the diamond-shaped signs (Signs C and D).

There were clear-cut differences in preference for different signs. All of the alternatives, other than Sign C, were ranked significantly higher than the W10-1 sign. As with the advance warning signs for passive crossings, the most-preferred alternatives were those that incorporated a supplementary panel with the W10-1; the two text-panel versions (Signs B and E) were significantly preferred to the icon version (Sign G). Considering the stated reasons for preference, the W10-1 sign was disliked primarily because it was seen as providing too little information or being uninformative. Sign C was disliked primarily because the image of the crossbuck and signal lights was seen as unclear and unfamiliar and also because it was felt that it was uninformative with too little information. The two most-preferred signs (Signs B and E) were felt to be informative and understandable (both image and text). Sign G was similar to B and E, but it used a crossbuck–and–signal lights icon instead of text on the supplementary panel. Some participants indicated that they found this configuration informative and attention getting, and others found the image to be unclear or confusing.

2.5.2.4 Rail-Highway Crossing Signs (at Crossing) for Passive Crossings

The current rail-highway crossing sign (R15-1 crossbuck) does not differ for active and passive crossings. If a version intended specifically for passive crossings is adopted, ideally it would convey that there is a rail-highway crossing located at the point of the sign; that there are no gates, lights, or other indications of the presence of a train; and that the driver is responsible for detecting and yielding to a train prior to the tracks. Across all alternatives, about 82 percent of answers indicated that the sign was well understood although only in about 15 percent of the answers could the response be coded as “fully correct.” The difference in comprehension scores for the various sign alternatives was statistically significant. The post-hoc comparisons indicated that the two regulatory signs (Stop and Yield signs) used alone (Signs F and J) were less well understood than were the other signs in the set, which were not statistically discriminable from one another. Signs F and J also suffered substantially higher rates of critical confusions (greater than 10 percent) largely because participants were not alerted to the presence of a rail-highway crossing. Not surprisingly, TCDs incorporating the Stop sign (Signs D, I, and J) had a high proportion (98.5 to 100 percent) of answers indicating that the driver must stop for the tracks, the sign, or both. Of the other TCDs, the R15-1 crossbuck (Sign A) had the highest proportion of responses (32 percent) that indicated a requirement to stop. This was substantially (and significantly) higher than when a Yield sign (Sign E) or (black-and-white) Buckeye panel (Sign C) was mounted below the crossbuck (17 to 18 percent); interestingly, when the crossbuck and Yield signs were mounted on separate posts (Sign H), the number of participants indicating a need to stop for the tracks was higher (26 percent). The Yield sign comounted with a To Trains panel (Sign G) also yielded a comparably low proportion of answers mandating a stop.

Preference rankings indicated that the most-preferred TCDs were those that combined a regulatory Stop or Yield sign with the crossbuck (Signs D, E, H, and I), particularly if comounted on the same post. The least-preferred alternatives were the Yield sign alone (Sign F), the crossbuck alone (Sign A), or the crossbuck with the Yield to Trains message on its arm (Sign B). The two alternatives combining a Stop sign with a crossbuck (Signs E and I) were, unsurprisingly, preferred for the same reasons: those who liked them were positive about the fact that they told the driver to stop. These signs were also felt to be understandable in both image and text, informative, easy to see, and attention getting. Interestingly, although the alternatives combining a Yield sign with the crossbuck (Signs E and H) also had high preference rankings, no specific reasons emerged from the responses as being dominant preference factors. For those participants who felt that it was desirable to require a driver to stop at a crossing, a frequent criticism of other alternatives was that they did not indicate a need to stop. The standard crossbuck (Sign A) was negatively viewed as being uninformative and not instructive, with too little information, and for not indicating that the driver should stop. The Yield sign, used alone (Sign F), was felt to be unclear and was thought to be a failure in giving warning and a failure for not indicating a requirement to stop. The most-frequent criticism of Sign B, which had Yield to Trains written across a crossbuck arm, was that the message was difficult to see and read. No dominant reasons for preference or dislike emerged for Sign C, which used the Buckeye panel (although in black and white rather than in its actual red-and-white coloring).

2.5.3 Summary of Findings—Comprehension and Preference Testing

Highlighted below are findings from the comprehension and preference testing.

- The W10-1 advance warning sign conveys the general concept of “rail crossing,” but is not well understood beyond this concept and has a relatively high rate of potentially dangerous confusions of meaning.
- No effective icon was found to convey the idea of a passive crossing. Concepts that had been previously suggested (e.g., the train icon or a signal head with a circle and slash) did not test well and were disliked.
- There was a frequent misperception (about 20 percent) that TCDs for passive crossings required a mandatory stop action.
- Although preference for the W10-1 sign alone was low, when it was combined with supplemental plates, comprehension was improved and preference was high. This was the case for both passive and active crossing cases.
- The R15-1 standard crossbuck conveys the general concept of “rail crossing,” but is not well understood beyond this general concept. Relative to alternatives tested, the crossbuck had a high rate of participants (33 percent) interpret it as requiring a mandatory stop.
- Preference for the crossbuck alone at a passive crossing was low. Preference for regulatory signs (i.e., a Stop or Yield sign) alone was low. However, the combined use of a crossbuck with a regulatory sign, particularly when the signs were comounted, was high.

The current standard TCDs alone do not fully convey the messages that one would like drivers to receive. New sign images do not appear very effective with the exception of the signal-lamp icon as a supplementary image. However, although the standard W10 advance warning sign and the R15-1 crossbuck are not entirely successful when alone, the strategy of combining them with other icon or text panels appears to result in TCDs that communicate more effectively and are preferred as clear messages by viewers.

2.6 EXPERT PANEL

Based on the findings of the preceding tasks, a preliminary set of alternative strategies for changes to the rail-highway grade crossing TCD system was developed as the basis for an expert panel meeting. The purpose of the meeting was to have independent outside experts review and comment on the findings and preliminary recommendations of the project.

A full-day workshop was held in Rockville, Maryland, in May 2001. The attendees (in addition to the Westat-BMI project team) included representatives from a range of agencies, as well as independent consultants to the project. Attendees represented the following agencies or areas of interest and positions:

- FRA—highway-rail crossing safety engineer;
- Mercer County, Illinois, Department of Public Works—county engineer;
- Texas DOT—state traffic engineer;
- West Virginia DOT—planning and research engineer;
- Maryland State Highway Administration—statewide studies team leader;
- Rail safety—consultant, formerly with a state commerce commission;
- Crossing safety—consultant, formerly a state DOT office director; and
- Human factors in highway and rail-crossing safety—consultant.

Because of last-minute conflicts, the invited representatives from a police agency and from the railroad industry were unable to attend, and replacements could not be obtained.

In preparation for the workshop, a summary report was provided to each participant. The report summarized the findings from the various research elements and presented several alternatives for recommended TCDs. The workshop began with the project team presenting an overview of the key findings and implications. Following this presentation, each participant was asked to provide initial comments, which were then followed by extended discussions.

There was no attempt to have the participants vote on recommendations for TCDs—rather, the intent was to have the participants comment on recommendations, provide alternative recommendations, and alert the research team as to potential implementation issues that could arise with any of the recommendations. A summary of key discussion points follows.

- Because most of the crossings with passive TCDs are on local roads, local agencies will be most affected by any changes to current devices. Also, because local agencies are least equipped (in both financial and staff resources), full implementation may be difficult. A funding mechanism may be required depending upon the implementation requirements. (Minority opinion was that because signs are regularly replaced, most implementation costs could be covered within regular maintenance budgets.)
- Implementation of the proposed TCDs is a critical issue particularly when it would require the installation of new signs on most of the existing crossbucks. Issues that need to be resolved include conformity with the Uniform Vehicle Code, sign height, maintenance and liability for signs, and enforceability. The states, federal regulators, local agencies, and railroads all have to buy in to the proposal.
- Consistency in TCD application across the country is paramount, and to ensure this, the recommended devices should be mandatory and specified as such in the *MUTCD*.
- General consensus was obtained on two issues: (1) the current crossbuck alone is not conveying all the information required by drivers; and (2) Stop signs should be used sparingly at crossings to preserve the message of a special hazard.
- The Buckeye crossbuck was considered inferior to other alternatives by all participants. The Yield message can be conveyed by existing signs, and the reflective “wings” have not proven to be effective in field operations. Similar improvements in conspicuity have been obtained by other methods that are in the current *MUTCD*.
- A minority of participants expressed concern about alternatives that require placing two standard warning signs on the same post. Other concerns included maintaining uniformity between urban and rural applications and in special situations (e.g., highways paralleling railroads) in which some signs might convey ambiguous messages about the duties of drivers on the parallel road.
- For suggestions involving the use of a Yield or Stop sign at the crossing, some participants questioned the need for a Yield Ahead or Stop Ahead sign if the line of sight to the crossing is unobstructed. This configuration has been the practice for highway-highway intersections in the *MUTCD*, but had not been addressed for rail crossings. However, Part 8 (Traffic Controls for Highway-Rail Grade Crossings) of the recent 2000 Millennium Edition of the *MUTCD* (*1*) now references the placement criteria for advance traffic control signs in Section 2C (Warning Signs).
- Recommendations for systems incorporating the use of the Yield sign (comounted with the crossbuck and as a Yield Ahead panel comounted with the W10-1 sign) were generally seen as preferred in terms of providing guidance to roadway users. However, some participants preferred other approaches because of the perceived potential for implementation problems.

The feedback from the workshop was used to help select and refine recommendations, clarify requirements, and develop an implementation plan and is reflected in the formal recommendations in Chapter 3.