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Administration**

Driver Behavior at Highway-Railroad Grade Crossings: A Literature Review from 1990–2006

**Office of Research
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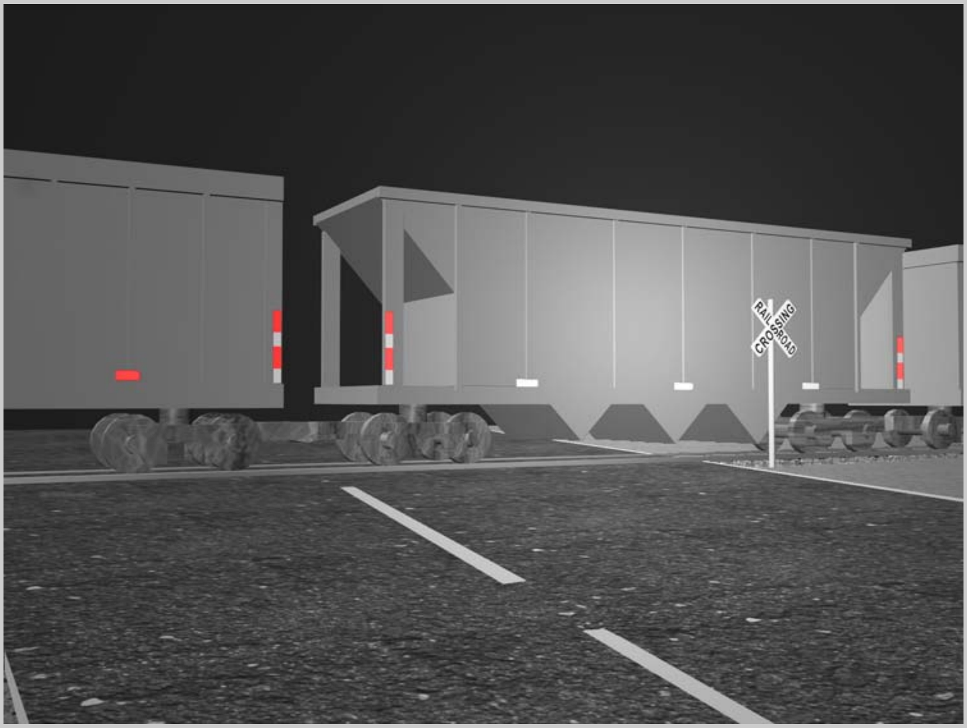
Washington DC 20590**

U.S. Department of Transportation
Research and Innovative Technology Administration
John A. Volpe National Transportation Systems Center
Cambridge, MA 02142-1093



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DOT/FRA/ORD-08/03

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13. ABSTRACT (Maximum 200 words)

Accidents at grade crossings continue to be the leading cause of fatalities in the railroad industry. A large proportion of these accidents are the result of driver error. The purpose of this report is to review research that addresses driver behavior at grade crossings to better understand the decisions and actions drivers make so that countermeasures can be developed to discourage dangerous driving behavior. This report is intended to update a 1990 literature review titled, *Driver Behavior at Rail-Highway Crossings*, by Lerner, Ratte, and Walker, that provided a comprehensive examination of factors contributing to driver noncompliance at grade crossings. This report focuses on grade crossing research conducted since 1990 and extends the review by Lerner, et al. by examining the grade crossing problem in the context of the general driving task. This literature review is organized using the framework of a sociotechnical model such that driver behavior is examined not as individual elements but as a system. Recommendations for additional research are also identified.

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ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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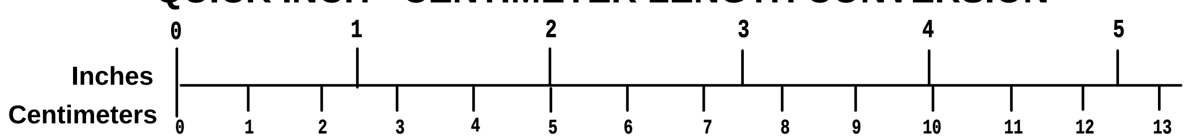
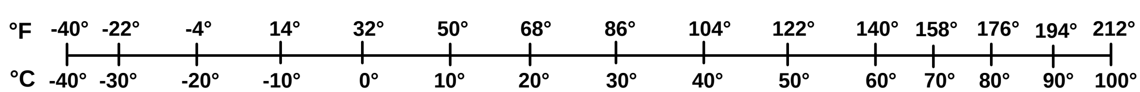


QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



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Feedback on this document can be sent to Dr. Michelle Yeh (Michelle.Yeh@volpe.dot.gov) or Dr. Jordan Multer (Jordan.Multer@volpe.dot.gov).

Contents

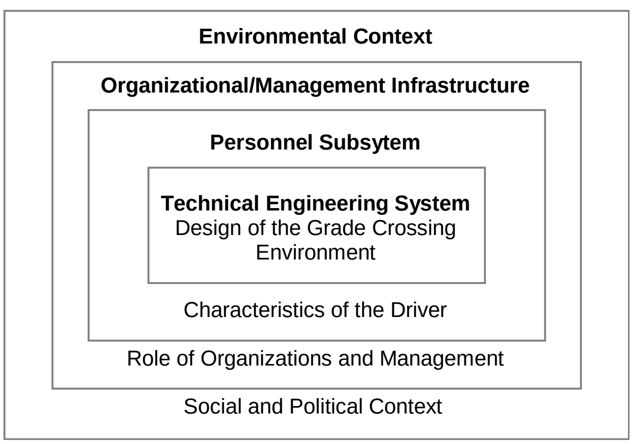
Illustrations

Executive Summary

The Federal Railroad Administration (FRA) working with the Federal Highway Administration (FHWA) and Federal Transit Administration (FTA) has significantly improved highway-rail grade crossing safety in the past decade. The *2004 Audit of the Highway-Rail Grade Crossing Safety Program* (Office of the Inspector General, 2004) reported that in the 10 years from 1994 through 2003, the number of grade crossing accidents decreased by 41 percent and the number of fatalities fell by 48 percent. Despite the reductions, accidents at grade crossings continue to be a significant concern to the railroad industry. A large proportion of these accidents result from driver error. In fact, the Office of the Inspector General attributed 94 percent of grade crossing accidents and 87 percent of grade crossing fatalities for that 10-year period to risky driver behavior or poor judgment.

This report is intended to update a 1990 literature review titled, *Driver Behavior at Rail-Highway Crossings*, by Lerner, Ratte, and Walker, that comprehensively addressed the roles of perception, knowledge, and driver attitudes in decision making at grade crossings and discussed countermeasures to encourage compliance. The goal of this report is to review research conducted since 1990 that addresses driver behavior at grade crossings and to provide further input for the development of countermeasures to discourage dangerous driving behavior. This report continues the literature review by Lerner, et al. and extends it by examining the grade crossing problem in the context of the general driving task as applicable to the grade crossing situation.

This literature review is organized using a sociotechnical model of the highway-rail grade crossing situation. This framework examines driver behavior at grade crossings through a systems perspective, with each element of the system examined with respect to how it interacts with other system elements. The sociotechnical model consists of four subsystems, summarized in the figure below.



At the center is the *technical/engineering system*. As defined here, this layer consists of elements of the grade crossing environment, techniques, and systems that assist the driver in detecting the crossing and presence of a train. How the driver processes the information from the grade crossing environment is represented by the second layer, the *personnel subsystem*. Factors influencing driver behavior may be classified into those that influence driving skill and those that influence driving style. The former concerns behavioral characteristics of human information processing that limit driver performance whereas the latter addresses biases and attitudes that affect how one chooses to drive by influencing one's perception of the situation.

Improvements to grade crossing safety will also require coordination among the different agencies involved, as shown by the *organizational/management infrastructure* layer. All these layers function within a political, cultural, and social environment, as highlighted by the outermost layer of the model, the *environmental context*. Regulatory oversight and public support or opposition to specific policies and actions also influences safety. The contribution of each layer of the model to grade crossing safety is reviewed briefly below. An operational summary of the recommendations from each layer is provided in Appendix A.

Technical/Engineering System

In considering the design of the grade crossing, several traffic control devices are present at the crossing (e.g., signs, pavement markings, and flashing lights), and some are also equipped with gates. With respect to signs, the results of the literature review show that drivers generally recognized the advance warning and crossbuck signs but did not know where they were located in relation to the crossing, when the signs were used, and the action required. Several research studies examined driver comprehension and compliance to alternative sign systems. Most of these sign systems consisted of a stop sign or yield sign presented in conjunction with the standard warning signs. The *Manual on Uniform Traffic Control Devices* (MUTCD) allows the use of stop or yield signs at passive grade crossings, where two or more trains operate daily. However, the use of stop signs at grade crossings is controversial. Compliance with stop signs at grade crossings is low, and the results of an accident analysis suggest that use of the stop sign may not reduce the accident risk at grade crossings relative to the presentation of the crossbuck alone. Additionally, there is concern that noncompliance at grade crossings could foster disrespect for stop signs in non-grade crossing situations. In light of these concerns, the FHWA clarified their position on the MUTCD provision by recommending that the yield sign be the default choice for traffic control and that use of the stop sign be limited to unusual situations where the need for vehicles to make a full stop is assessed through an engineering study or judgment. Research examining use of the yield sign or incorporating a yield message into the sign system show that the driver's understanding of the action required is improved relative to a crossbuck alone, but its effect on driver behavior was mixed.

Flashing lights and gates provide active protection at a grade crossing, signaling to drivers when a train is in close proximity. However, observations of behavior at active grade crossings indicated that drivers were quite willing to violate active warning signals. Compliance at actively protected crossings may be improved in two ways: *explicitly* by increasing the level of protection to prevent drivers from violating the crossing (e.g., by installing barrier-type systems such as four-quadrant gates and median barriers), or *implicitly* by improving the credibility of the warning signals (e.g., with constant time warning systems to reduce waiting time, identifying signal malfunctions to reduce the false alarm rate at the crossing, or incorporating highway traffic signals that have high credibility in the general driving situation).

Noncompliance may also be due to a failure by the driver to detect the grade crossing or train, particularly at crossings that lack active protection. The detectability of the crossing may be improved by simply illuminating the crossing, presenting strobe lights in conjunction with signs at the crossing, and reflectorizing the crossbuck and crossbuck post. To optimize the use of reflectorization, the MUTCD requires that the crossbuck and crossbuck post be reflectorized and that reflective sheeting be applied on the front and back along the full length of the crossbuck posts.

The train itself is equipped with alerting lights, reflective markings, and a horn to facilitate its detection. Regulations regarding their use are provided in the *Railroad Locomotive Safety Standards: Clarifying Amendments; Headlights and Auxiliary Lights; Final Rule* (codified in 49 Code of Federal Regulations (CFR) § 229); *Reflectorization of Rail Freight Rolling Stock; Final Rule* (codified in 49 CFR § 224); and *Use of Locomotive Horns at Highway-Rail Grade Crossings; Final Rule* (codified in 49 CFR § 222 and 229). Field tests have shown the effectiveness of alerting lights and reflective markings. Participants detected trains equipped with these devices at further distances than trains equipped with the headlight alone or trains without reflective markings. The train horn is a secondary alerting system, with one significant disadvantage; its effectiveness is limited by the dampening of its sound (e.g., from background noise associated with the specific location, interior noise in the vehicle, community whistle bans, or insertion loss as the sound tries to penetrate the vehicle shell). An alternative auditory warning system is a wayside horn, mounted at the crossing. Results of field tests showed that its use had no negative impact on safety relative to the sounding of a train horn, while at the same time, it had a positive impact on nearby communities by reducing the noise level.

Personnel Subsystem

Safety improvements at the technical/engineering system level must be evaluated with respect to the *personnel system*, that is, the driver. Characteristics inherent to the driver relate to skill level and driving style. With respect to the former, driving skill is affected by age, experience, internal or external distractions, and driver impairment. Aging results in changes in one's perceptual and cognitive abilities, and these changes may hinder one's ability to detect and respond to cues at grade crossings. Lack of experience, particularly for young drivers, led to a less than efficient visual search strategy and underestimation of potential driving hazards. The effects of internal and external distractions and driver impairment (e.g., due to alcohol use and fatigue) are similar. Both prevent the driver from detecting a grade crossing or approaching train in a timely manner. Countermeasures to compensate for reduced driving skill, in particular the effects of aging and experience, include techniques for facilitating detection of the crossing at night (e.g., reflectorization of trackside objects) and installing additional signs at the crossing to indicate the action required.

With respect to driving style, drivers' decisions how to drive influences the perception of the dangers posed by a grade crossing and the decision whether to comply. Generally, drivers do not expect to encounter a train at a grade crossing and sometimes do not even look for a train. This behavior is partially attributable to familiarity with an area; drivers who were familiar with a crossing were *more* likely to be involved in a grade crossing incident than drivers unfamiliar with the crossing. However, some drivers are simply risk-takers and find noncompliant behavior exciting (e.g., beating a train across the tracks). Although risk-takers understood the consequences of their actions, they tended to be overconfident in their driving skill and optimistic in their abilities to avoid an accident.

These attitudes in driving style are moderated by gender differences and age. Statistics showed that male drivers committed more violations and were involved in more grade crossing accidents than female drivers. In addition, young drivers were more aggressive in their driving style than older drivers. Studies addressing drivers' attitudes towards committing violations in the general driving situation reported that males and young drivers were less concerned with the negative outcomes of committing violations than their counterparts, viewed the risk of negative outcomes as being less likely, and possessed a sense that committing the violation was out of their control.

Because driving style reflects a driver's personality, it will be more difficult to change than driving skill.

Organizational/Management Infrastructure

Efforts to improve grade crossing safety require coordination and collaboration among federal, state, and local agencies, as described by the *organization/management infrastructure* layer of the sociotechnical model. Coordination among public agencies, railroad companies, and highway engineers may be necessary to identify which crossings to improve and determine what those improvements should be. The FRA maintains a crossing inventory and accident/incident database of public and private grade crossings that can be used by states to determine which crossings to improve, but input to the inventory and database is voluntary and therefore problematic. Coordination among rail and state agencies is needed to ensure that the inventory includes all grade crossings and contains accurate information regarding the level of protection at the crossing. Additionally, coordination between these agencies and the public may be necessary to address the public's concerns about the impact of the changes on traffic, on their neighborhood, and on their convenience.

One example of successful collaboration among states, railroad companies, and industry is in the development, implementation, and evaluation of Intelligent Transportation Systems (ITS) technologies. These systems include in-vehicle displays to alert drivers to the presence of grade crossings and approaching trains, variable message signs located along freeways to inform drivers of approaching trains at crossings near freeway exits so drivers can select alternate routes, and "intelligent grade crossings" where intelligent rail and automotive technologies are integrated. The effectiveness of these systems depended on their accuracy. In field evaluations of in-vehicle ITS technologies, drivers did not trust systems with a high rate of false alarms and perceived the systems to be unnecessary, particularly when used at active grade crossings.

Environmental Context

The *environmental context*, the outermost layer of the sociotechnical model, addresses the oversight and the social and cultural impact of actions by regulatory authorities. This layer encompasses the development of policies requiring safe practices, educating the public to the driving rules at grade crossings, and the enforcement of those rules. It also includes the state legislatures and court system that adjudicates the rules. The failure to recognize the political, social, and cultural forces in this process can prevent the implementation of valid safety improvements or result in an ineffective implementation.

The FRA recently finalized a rule requiring trains to sound their horns when approaching public crossings and specified guidelines for communities who want to implement safe alternatives to the train horn (see *Use of Locomotive Horns at Highway-Rail Grade Crossings; Final Rule,* 49 CFR § 222). In developing this rule, the FRA reached out to communities, local municipalities, state agencies, and railroads to balance safety concerns with quality of life issues. Additionally, the FRA, in partnership with Operation Lifesaver, has worked with state and local agencies, the rail industry, and other transportation organizations to inform the public about the dangers of highway-rail crossings. The FRA has also worked with local law authorities to improve enforcement at grade crossings through automated photo enforcement. Several states in the United States and one province in Canada have conducted demonstrations of this technology and reported positive impacts when its use was publicized and where consequences were tangible.

However, judges in some states have noted concerns about the process for admitting digital photos as evidence and if violators were sufficiently notified of their rights and responsibilities.

Areas for Further Research

Based on the results of the literature review, additional research is recommended in the following areas:

- Evaluate the use of highway intersection-related traffic control devices, in particular the use of stop and yield signs, at passive grade crossings,
- Examine the use of traffic calming techniques at grade crossings,
- Conduct a cost-benefit analysis to determine the impact of different factors that contribute to driving style,
- Examine methods for improving drivers' perception of signal reliability,
- Conduct further research in the use of ITS technologies, and
- Evaluate different approaches to educating drivers. In particular, examine methods that deviate from traditional approaches to education and take advantage of current technologies such as the Internet.

1 Introduction

The Federal Railroad Administration (FRA) working with the Federal Highway Administration (FHWA) and Federal Transit Administration (FTA) has significantly improved highway-rail grade crossing safety in the past decade. The *2004 Audit of the Highway-Rail Grade Crossing Safety Program* (Office of the Inspector General, 2004) reported that in the 10 years from 1994 through 2003, the number of grade crossing accidents decreased by 41 percent and the number of fatalities fell by 48 percent. However, accidents at grade crossings continue to be a significant concern to the railroad industry, and a large proportion of these accidents are the result of driver error. In fact, the Office of the Inspector General attributed 94 percent of grade crossing accidents and 87 percent of grade-crossing fatalities from 1994 through 2003 to risky driver behavior or poor judgment. In 2003 alone, 93 percent of accidents at grade crossings and 83 percent of fatalities resulted from drivers who failed to stop at a crossing, drove through the crossing, drove around activated automatic gates, or stopped their vehicles on the crossing (Office of the Inspector General, 2004).

This report is intended to update a 1990 literature review titled, *Driver Behavior at Rail-Highway Crossings*, by Lerner, Ratte, and Walker, that provided a comprehensive examination of factors contributing to driver noncompliance at grade crossings. The Lerner, et al., report addressed the roles of perception, knowledge, and driver attitudes in decision making at grade crossings and discussed countermeasures developed to discourage noncompliance. The goal of this report is to review research conducted since 1990 that addresses driver behavior at grade crossings, which may be used to develop countermeasures to discourage dangerous driving behavior at grade crossings. This report updates the literature review published by Lerner, et al. and extends it by examining driver behavior at grade crossings in the context of the general driving task.

1.1 Background

A highway-rail grade crossing[1] can be compared to a highway intersection with two conflicting streams of traffic, but it is unique in that it is a multimodal intersection in which the train always has the right-of-way. A train moves along a fixed path, limiting the avoidance maneuvers that the locomotive engineer can take, and its operating characteristics prevent the operator from braking quickly to avoid a collision. Drivers sometimes underestimate the danger at grade crossings and engage in behavior that increases the likelihood of an accident.

In 1994, the Secretary of Transportation issued the first Rail-Highway Crossing Safety Action Plan, with the goal of reducing highway-rail grade-crossing collisions and fatalities by at least 50 percent over a 10-year period. The Action Plan, developed by the FRA, FHWA, FTA, and the National Highway Traffic Safety Administration (NHTSA), proposed six initiatives for improving crossing safety:

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[1] Highway-rail grade crossings are also referred to as “highway-rail crossings”, “highway-rail intersections”, “railroad crossings”, “grade crossings”, or simply “crossings”. These terms are used interchangeably in this review.

1. Increasing enforcement at grade crossings,
2. Conducting comprehensive reviews of all crossings using a systems approach by examining crossings in a corridor to determine candidates for potential closure or consolidation and upgrades,
3. Increasing public education and expanding the Operation Lifesaver program,
4. Improving safety at private crossings,
5. Conducting research on signs, signals, lights, and pavement markings and demonstrating the use of innovative technologies, and
6. Preventing trespassers.

An audit by the Office of the Inspector General (2004) noted that the United States (US) Department of Transportation (DOT) came close to meeting its goal of reducing grade crossing accidents by 50 percent. From the end of 1993 to the end of 2003, the number of grade crossing accidents decreased by 41 percent and the number of fatalities decreased by 48 percent. However, much of the improvements in grade crossing safety were attributed to closures of public and private grade crossing, upgrading passive crossings with active warning devices, and public education campaigns (Office of the Inspector General, 2005). Consequently, achieving the same scale of reduction in accidents and incidents will be difficult without a better understanding of remaining problem areas.

One of these problem areas is driver behavior at grade crossings. Several research reviews have addressed this problem. In 1990, Lerner, Ratte, and Walker published a comprehensive report titled, *Driver Behavior at Rail-Highway Crossings*, that addressed contributing factors and driver characteristics associated with behavior at grade crossings and presented the results of research examining countermeasures to improve compliance prior to 1989. Westat (1999) updated the report in a review of research published after 1989 that discussed the effectiveness of various grade crossing traffic control devices. However, the review focused specifically on passive crossings and countermeasures appropriate at those crossings. As part of Canada's efforts to reduce grade crossing accidents, Caird, Creaser, Edwards, and Dewar (2002) conducted a comprehensive literature review examining behavioral contributors to grade crossing accidents in the US and applied their findings to Canadian crossings. Their review addressed research examining the effectiveness of countermeasures at US grade crossings to develop a taxonomy to understand patterns of driver error. Caird, et al. focused on the characteristics of the crossing, the traffic control devices used at crossings, and driver characteristics contributing to compliance but did not address factors in the perception and detection of trains at or approaching the crossing that also contribute to compliance.

This document is intended to complement the previous reviews, and in particular, provide a comprehensive update to Lerner, et al. (1990). Specifically, this report will review relevant research, conducted since the publication of Lerner, et al., that addresses driver behavior at grade crossings and present the results of evaluations examining the effectiveness of current and proposed countermeasures. This literature review extends the previous reviews by addressing the grade crossing problem using a systems perspective. Driver compliance at grade crossings is considered not only with regard to features of the crossing and train and characteristics of the driver, but also in light of the actions of organizations involved in improving grade crossing safety and the impact of economic, political, and social forces. To make further progress in improving grade crossing safety, all these factors and their interactions must be better understood.

1.2 Method

Relevant literature was identified through bibliographic searches, a review of academic journals and government reports, review of bibliographies from prior research, and Internet searches. The review of articles and research studies focused on those that addressed human behavior at grade crossings. Because negotiating a grade crossing is only one aspect of the driving task, research addressing general driving behavior was included when relevant to the grade crossing problem. This document includes literature addressing the effectiveness of countermeasures on driver compliance but does not include discussions of the technical aspects of grade crossing and locomotive technologies (e.g., the costs of installation and/or maintenance or traffic engineering issues).

1.3 Organization of this Report

This literature review is organized in the framework of a sociotechnical model (first proposed in Moray and Huey, 1998 and applied to the rail domain in Moray, 2006). This approach allows driver behavior at grade crossings to be examined not as individual elements but as a system and thus considers each element of the system with respect to how it interacts with other elements of the system. The system can be described in various ways and at many levels. Figure 1 depicts the representation describing the problem of driver behavior at grade crossings used here.

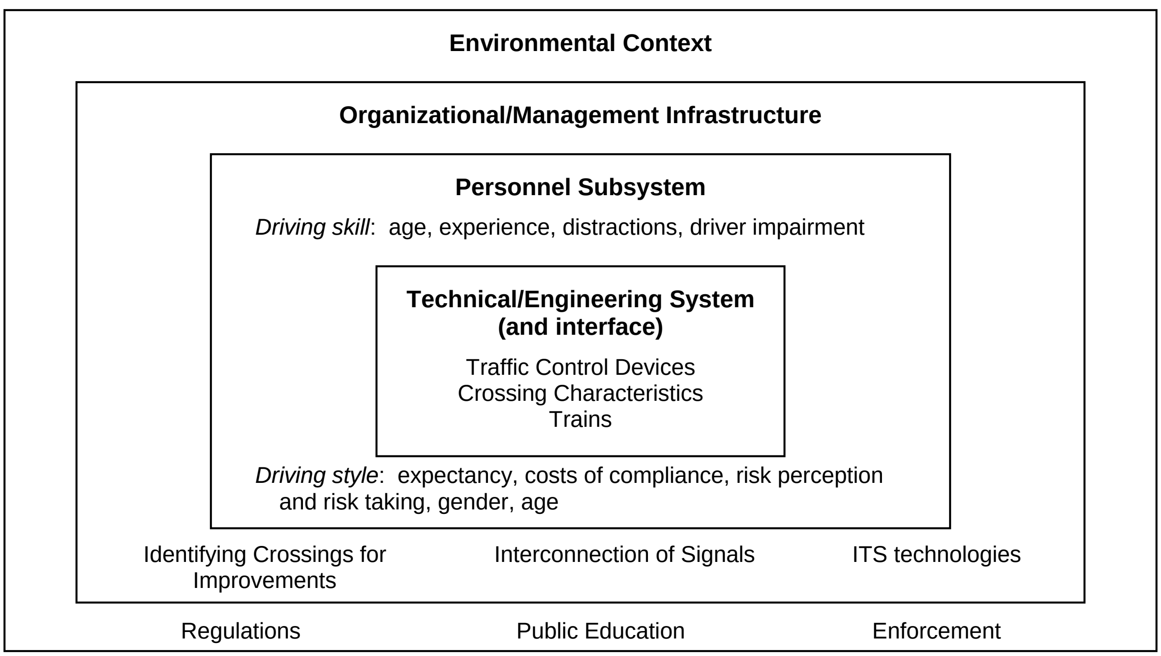


Figure 1. Sociotechnical model of the highway-rail grade crossing domain.

As shown in Figure 1, the sociotechnical model consists of four subsystems. The innermost layer is the *technical/engineering system*, which is defined here to consist of elements and characteristics of the grade crossing environment (e.g., traffic control devices) and the train. How this information is processed by drivers will depend not only on the design of the components of the technical system but also on the drivers' cognitive and perceptual processes and social factors, as represented by the *personnel subsystem*. Factors influencing driver behavior may be classified into two types: those that influence driving skill and those that influence driving style. Driving skill consists of behavioral characteristics of human information processing that limit driver performance. Characteristics such as age, experience, distractions, and impairment due to alcohol use or fatigue change one's skill level. On the other hand, driving style refers to biases and attitudes that affect how one chooses to drive. Driving style is shaped by expectancy, the costs of complying with warning devices at grade crossings, risk perception and risk taking, and moderated by gender and age differences. Note that age-related effects are a factor in both driving skill and driving style. For the former, increasing age impairs information processing and for the latter, it moderates the level of risk a driver is willing to accept.

Improving grade crossing safety requires coordination among agencies at the federal, state, and local levels, as shown by the *organizational/management infrastructure* layer. Examples of this coordination include efforts to identify which crossings to improve, how to interconnect highway signals and grade crossing warning devices, and research and development in the use of Intelligent Transportation Systems (ITS) technologies.

All these layers function within a political and social context. That is, public support or opposition and the specific policies and actions of regulators also influence safety. This is highlighted by the outermost layer of the model, the *environmental context*, which addresses the regulatory oversight and the public pressures imposed on regulatory authorities. This layer includes developing policies requiring safe practices, educating the public to the driving rules at grade crossings, and enforcing those rules. In particular, the actions of state legislatures and courts impact the effectiveness of the rules based on how the rules are adjudicated.

This report reviews research addressing the topics in each of the layers shown in Figure 1. Section 2 begins by summarizing the findings by Lerner, et al. (1990) in the context of a sociotechnical system. Sections 3 through 6 present research and literature published since 1990 that address the different layers of the model. Section 3 focuses on the technical/engineering system; Section 4 reviews literature pertaining to the personnel subsystem; Section 5 addresses the organizational/management infrastructure; and Section 6 discusses the impact of regulatory oversight and the political and social environment on improving compliance. Section 7 presents a summary of the findings and recommends areas where new research is needed. To facilitate implementation of the findings, operational recommendations based on the results of the literature review is provided in Appendix A.

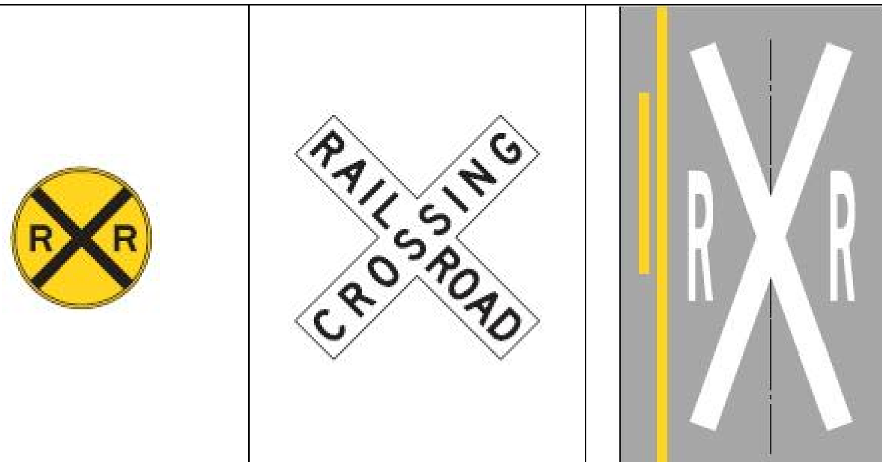
Note that several documents contain guidance for maintaining safety at grade crossings. The *Manual on Uniform Traffic Control Devices* (MUTCD; FHWA, 2003) provides standards for traffic control devices (signs, signals, and pavement markings) and their placement at the crossing. The *Guidance on Traffic Control Devices at Highway-Rail Grade Crossings* (FHWA, 2002) provides more detailed guidance to aid in decisions regarding their selection and installation. The *Railroad-Highway Grade Crossing Handbook—Revised Second Edition 2007* (FHWA, 2007) is a reference for improving grade crossings, and *A Policy on Geometric Design of Highways and Streets* (American Association of State Highway and Transportation Officials (AASHTO), 2000) provides specifications for critical dimensions, such as formulas for calculating sight distance requirements at grade crossings, and specifications for safe vertical and horizontal roadway alignments.

2 Review of Driver Behavior at Rail-Highway Crossings

The report, *Driver Behavior at Rail-Highway Crossings*, by Lerner, et al. (1990), provides a comprehensive review of human factors issues contributing to driver behavior at grade crossings and the effectiveness of countermeasures developed to improve this behavior. This section summarizes the findings in the Lerner, et al. report using the framework of the sociotechnical model presented in Figure 1.

2.1 Technical/Engineering System

The information at a grade crossing provides several cues and features to assist the driver in detecting the crossing and the presence of a train. Public crossings have advance warning signs (see Figure 2a), a crossbuck (Figure 2b) and pavement markings (Figure 2c), and some are equipped with active warning devices such as flashing lights or gates that indicate the presence of a train.



(a) Advance Warning Sign (W10-1) | (b) Crossbuck (R15-1) | (c) Pavement Marking

Figure 2. Signs and markings at grade crossings.

However, characteristics of the crossing, such as sight distance or its visibility at night may hinder detection of the train at the crossing. Methods to improve the conspicuity of the train at the crossing (e.g., by removing sight restrictions or illuminating the crossing) and as the train approaches and enters the crossing (e.g., headlights, reflectorization, and train horn) will be discussed.

2.1.1 Traffic Control Devices

Drivers generally understand that they are approaching a grade crossing upon seeing one of five traffic control devices: the crossbuck, advance warning sign, pavement markings, flashing light signals, or automatic gates. However, drivers do not understand their precise meaning, the action required, and their location at the grade crossing. Additionally, drivers' comprehension of pavement markings is unclear. With respect to active warning devices, drivers generally know the meaning conveyed by flashing lights and automatic gates although they do not always comply with them. Each of these warning devices will be discussed in more detail below.

2.1.1.1 Signs

Numerous studies have extensively addressed driver detection and comprehension of the advance warning and crossbuck signs. The unique shapes of these signs (i.e., the advance warning sign is round and the crossbuck is "X-shaped") draws drivers' attention to the crossing but may also violate driver expectations about what a warning sign should look like. In fact, the Manual on Uniform Traffic Control Devices (MUTCD) requires that warning signs be diamond-shaped. With respect to comprehension, studies consistently find that drivers do not understand the distinction between the crossbuck and the advance warning sign and are unaware of the action required.

Proposed alternatives to the standard signs have attempted to improve their conspicuity and driver comprehension. The conspicuity of a sign depends not only on characteristics of the sign itself, such as its color and size, but also on its location at the crossing and the contrast of the sign with respect to its immediate surroundings. Prototype advance warning signs described by Lerner, et al. (1990) used a diamond-shape to conform to stereotypes of warning shapes and varied their color used in signage. Whereas drivers generally understood these advance warning sign alternatives as indicating the presence of a crossing, the comprehension rate for these signs were not as high as that for the standard advance warning sign. Moreover, their use did not show a significant benefit for alerting drivers to the presence of a crossing.

Studies evaluating the comprehension of alternative crossbuck signs have found that the shape of the crossbuck conveyed meaning to drivers. Prototype crossbuck designs varied by color, the angle between the blades, and the presence of the "Railway Crossing" message. These prototype designs improved the conspicuity of the crossbuck, although in the evaluation, the presentation of the experimental crossbucks was atypical of the driving environment. In the study, participants viewed the experimental crossbucks against a uniform background, and the success of the crossbuck design varied depending on the background color.

Lerner, et al. note that a major limitation of the advance warning and crossbuck signs is that they provide no information regarding whether a crossing is equipped with active warning devices or not. Of concern is the fact that many drivers believe that active warning devices are used at all, or most, grade crossings, and thus, the absence of an active warning system could be interpreted as signaling the absence of a train. Various foreign countries use distinctive active and passive crossing signs, but no data were available regarding the effectiveness of the signs in helping drivers recognize the type of crossings ahead when Lerner, et al. reviewed the literature. Other proposed alternative sign systems have attempted to enhance the information provided by warning devices. The supplementary signs indicated to the driver when it was safe to proceed, the status of the signals system (i.e., whether or not it is malfunctioning), and information about the approaching train. The benefits of these sign systems were unknown.

2.1.1.2 Pavement markings

Pavement markings consist of an "X," the letters "RR," a no passing marking on two-lane highways with marked centerlines, and transverse lines. When shown three different illustrations of pavement markings (the standard marking versus ones that show an RR or an X, but not both), 70 percent of drivers identified the correct one. Because the integrity of the pavement markings may degrade over time (e.g., due to wear from tires), alternative markings that eliminated the RR or reduced the size of the X were evaluated. However, the level of comprehension for each of the markings, and the contribution of the letters (X, RR) to comprehension, was not clear because the order in which participants viewed the markings was not varied in the study, and the results showed increasing accuracy through the sequence of markings.

In addition to pavement markings, rumble strips may call attention to the presence of a grade crossing. Rumble strips provide kinesthetic and auditory information, so they can alert the driver if he/she is visually distracted. Evaluations of rumble strips showed that drivers responded to the presence of a grade crossing faster than at crossings without rumble strips, and painting the rumble strips increased their visibility and reduced approach speeds to the intersection. However, although rumble strips promoted compliance, in some cases, they also promoted unsafe avoidance behavior. For example, observations showed that some drivers moved into the opposing lane to avoid the rumble strips.

2.1.1.3 Active warning devices

Studies evaluating driver comprehension of active warning devices indicated that drivers understood that the onset of flashing lights meant that "a train is coming" and that they must stop, but they did not know what action to take afterwards. In some states, drivers may proceed at flashing-light only grade crossings once the train has passed and they deem it safe to do so; however, many drivers did not realize that they had this option, believing instead that they needed to wait until the flashing stopped. Other drivers understood the meaning of the flashing lights but did not comply. Violations were highest at crossing protected only by flashing lights, signals, and signs, that is, at crossings where there is no physical barrier. In fact, in one observational study, more than half the drivers who encountered the crossing failed to comply with flashing light signals, even though they saw the flashing light signal in advance.

The tightly-focused narrow beams of the flashing lights that signal the approach of a train may hinder detection. Although designed to maximize intensity, the beams may be difficult to detect at close distances to the crossing under non-ideal viewing conditions, when small deviations in where the signal is aimed, or when variation is in the driver's viewing angle on the approach to the crossing (e.g., curves or grade changes on the roadway). Efforts to increase the conspicuity of the flashing light signal focused on varying the parameters of the signals, such as its intensity, size, color, and flash rate, but there was little objective evidence that optimization of these parameters increased the effectiveness of the alert. The use of alternately flashing strobe lights, mounted above or below the conventional flashing lights, was more successful. Subjective judgments obtained from field studies indicated that the strobe lights increased the visibility of the signal system. When strobe lights were added to gate arms, drivers' decelerated earlier and approached the crossing at slower speeds than without the strobe lights. Whether the increased conspicuity of the flashing lights provided by the strobe lights improved driver compliance in the long-term was not addressed.

2.1.2 Crossing Characteristics

Poor visibility of the train at the crossing is often a contributing factor when a vehicle strikes a train. Lerner, et al. noted that the number of these incidents was greater at night than in daylight, with many of these nighttime accidents occurring at crossings that were not illuminated. This fact highlighted not only the difficulty of detecting the train at night, but also the difficulty of detecting the crossing. Additionally, becoming alerted to the presence of an approaching train is important for negotiating grade crossings, but in a large percentage of crossing accidents, drivers failed to detect an approaching train before it reached the crossing. Evidence suggests that a critical factor is inadequate sight distance that prevents the driver from scanning the tracks at a far enough distance from the crossing to make the decision of whether to stop or proceed. Countermeasures to improve the conspicuity of the crossing and to inform drivers of sight restrictions are addressed below.

2.1.2.1 Illumination

Illumination of the crossing improves detection of the crossing at night, particularly for passive grade crossings. Illumination can also be effective at crossings with the following characteristics: nighttime train activity, low train speeds, high rate of accidents caused by drivers failing to detect trains at night, crossings that are occupied for long periods at night, limited sight distance, and low illumination levels. Reflectorizing trackside objects (e.g., the backs of crossbucks or other track hardware) can also call attention to the grade crossing, particularly when a train is occupying the crossing. In this case, vehicle headlights, intermittently reflected off the backs of the signs as the train passes through the crossing, will create a strobe-like effect. No formal evaluations regarding the use of reflectorization at the crossing were available at the time Lerner, et al. conducted their review.

2.1.2.2 Sight Restrictions

Limited sight distance to the crossing, along the track when approaching the crossing or when stopped at the crossing, hinders drivers' ability to detect an oncoming train and is a critical accident factor at passive grade crossings. Sight restrictions limit the time available for the driver to respond to the grade-crossing situation and affects drivers' ability to judge the speed and distance of an approaching train where cues regarding time and distance are more available with an unrestricted lateral view. However, drivers are usually not aware when sight restrictions exist, and even when they are aware, they do not adjust their driving behavior accordingly. Signs at crossings with limited sight distance that indicate the sight restriction and provide the appropriate approach speed and the point on the approach at which the driver should search for trains may improve driver behavior. Additionally, the site could be physically improved by removing visibility obstructions.

2.1.2.3 Increasing Crossing Conspicuity

Tests of active advance warning devices presented in conjunction with warning signs have examined their impact on increasing the conspicuity of the crossing. In one study, flashing yellow beacons, located above and below warning signs, were installed at active grade crossings with restricted sight distance. The active advance warning devices appeared to improve detection of the crossing, although the unique characteristics of the grade crossings used in the evaluation limited the generalizability of the results. During the day, the flashing beacons were effective when they were active before the crossing signal; at night, they were effective if they flashed continuously.

2.1.3 Trains

The difficulty in detecting a train when it is already on the crossing may account for approximately 25 percent of accidents at passive crossings and for about 10 percent of all vehicle-train collisions. Trains are equipped with several devices to facilitate their detectability: headlights, reflective markings, and a horn. However, there are limitations to the effectiveness of these devices.

First, the standard locomotive headlight is not easily visible under all viewing conditions. During the day, its visibility is limited by its narrow beam width; at night, the light may not be distinctive from other moving light sources. Several studies have examined alternatives to the standard headlight (e.g., an oscillating headlight that rotates 15º to the right and left and partially illuminated panels along the sides of railcars). In particular, the use of roof-mounted xenon strobe lights received much attention. The results of evaluations indicated that these lights were detectable from larger viewing angles and greater distances than the standard headlight, but their detectability may have been facilitated by participants' expectancy for seeing a strobe-equipped train. As a result, more testing is needed to fully evaluate their effectiveness in facilitating detection of trains in normal crossing conditions.

Second, with regards to the use of reflective markings, reflectors improved train visibility when there were no visual obstructions at the crossing and when the driver had an adequate visibility of the crossing on the approach. However, the intensity of reflective markings degraded over time as the reflectors deteriorated with age or dirt accumulation on the reflectors. Thus, constant maintenance of the reflectors is required for reflectorization to be effective.

Finally, although the train horn has the advantage in alerting the driver by not requiring the driver to be oriented towards its signal, other sounds may limit its effectiveness (e.g., noise from neighboring communities, background noise and insertion loss in a car, or environmental noise). A general consensus is that the use of on-train auditory warning devices is not an effective primary warning device. Consequently, alternative auditory signals have not been evaluated extensively.

2.2 Personnel subsystem

Non-compliance at grade crossings may be the result of error due to a deficiency in *driving skill*, such as lack of knowledge. For example, a significant number of drivers do not recognize that they are primarily responsible for avoiding accidents at grade crossings nor do they possess a clear responsibility of what action is required. However, some drivers simply choose not to comply with the action required, a decision formed through intention and how one chooses to drive; that is, their *driving style*. Each of these factors is addressed below.

2.2.1 Driving skill

At a grade crossing, the driver must determine whether he/she can safely cross the tracks prior to a train's arrival. Drivers must look for the train, judge its arrival time, and judge their own time to clear the tracks. Perception occurs primarily in the visual system; auditory and kinesthetic systems may contribute to detection of the train and crossing but provide little information towards estimating train speed, distance, and closing rate.

Several errors in the detection and identification process can arise. Detection requires becoming aware that an object is present whereas identification involves determining what the object is and understanding its attributes. First, at low levels of illumination, detection of speed and distance cues is poor and identification is hindered due to low visibility. Train detection occurs primarily in one's peripheral vision, which is more sensitive to movements than foveal vision but does not have as good an acuity. When a train is detected, one turns in the direction of movement to bring it into focus and to identify it. Low illumination at night hinders this identification process. Second, restricted sight distance at the crossing further limits the time the driver has to determine the train's speed and arrival time. Third, drivers do not always complete a sufficient scan of the grade crossing to look for trains; studies examining drivers looking behavior at crossings indicated that 15–35 percent of drivers did not even look for an approaching train.

Estimates of train speed and distance are also subject to several misjudgments in motion and gap perception. While little data exists on speed judgments for trains at a grade crossing, several studies examined how well drivers estimated the speed and distance of approaching vehicles in highway situations. The results indicated that these judgments were subject to a number of errors and were often inaccurate. With respect to the grade crossing situation, some unique features of trains and crossings can contribute to misjudgments in speed and distance. First, perception of train speed is subject to the "large object illusion," in which the speed of larger objects is perceived to be slower than that of smaller objects, even when both are moving at the same speed. Second, the viewing angle and sight distance at the crossing influence the driver's perception of train distance. Depth cues, such as the convergence of the railroad tracks, may lead to overestimates of the train's distance from the crossing. Third, the rate of retinal displacement (i.e., the rate at which the size of the image changes on the retina, which provides cues to speed) is small. Virtually no change occurs in the size of an approaching train until it is close. Fourth, drivers fail to properly incorporate the speed of other vehicles into gap judgments.

Judgments of train speed and distance are also more difficult in nighttime viewing conditions. The degree of separation between automobile headlights provides distance information but the separation of headlights on a train is so close that the headlights may appear as a single source of light from a distance. Additionally, pursuit tracking of the train headlight to obtain its speed and distance is subject to lag, resulting in underestimations. Pursuit tracking is a function of the eye-head movement system; when tracking a moving target against a nondescript background, the major source of information comes from the path and speed of the eye movements. However, this tracking is not perfect, and the eye may lag the target. The amount of this lag increases as the speed of the target increases, and may result in underestimations of the train speed.

Countermeasures to improve the driver's judgment of his/her own vehicle speed and distance or train vehicle speed and distance have focused on methods that create or capitalize on visual illusions at the grade crossings to distort judgments of vehicle speed or train speed in order to induce the driver to slow down. However, Lerner, et al. warns that altering one's perception of speed may have an unintended, opposite effect such that the driver speeds up more to try to beat the train across the track.

Alcohol use, drug use, or fatigue also limits a driver's perceptual performance and decision making. Much research exists addressing the effect of these factors in the general highway driving situation but little research is available regarding the contribution of these factors to grade crossing accidents. Studies that are available suggest that alcohol use is a significant contributing factor to nighttime grade-crossing accidents. It is expected that drug use and fatigue could increase the accident risk, but the incidence rate is not known.

2.2.2 Driving style

One's driving style, that is, how one chooses to drive, influences how the information acquired about a grade crossing is processed and applied. The decision to comply at a grade crossing is influenced by one's expectancies regarding the likelihood of a train and about the crossing itself. Studies showed that drivers' estimates of train volume were based on their familiarity with the area. Consequently, drivers who are familiar with a crossing will be *less* likely to look for a train at the crossing or to reduce their speed on their approach to the crossing than drivers who are *un*familiar with the crossing. At active crossings, expectancies regarding the credibility of the warning device and warning time, developed from past experiences, may be a factor in one's decision to comply. If a high number of false alarms occur or if the delay between the onset of the warning and the train arrival is long, then over time, the driver may perceive warnings at crossings as being unreliable so that the warning becomes less effective.

Compliance must also be weighted with its costs. Stopping and waiting for a train results in delays, and slowing when approaching a crossing increases one's likelihood of having to stop for an approaching train. Additionally, sometimes safety concerns preclude compliance. For example, speed variability at grade crossings increases the highway accident rate, so by slowing down for a train, the driver increases the likelihood for an accident with a close-following vehicle. In fact, Mortimer (1988) noted that a large proportion of grade crossing accidents were not train-vehicle collisions but vehicle-vehicle collisions, and in particular, rear-end crashes.

Of concern is the behavior of risk-takers. Studies reported that drivers exhibiting dangerous behavior at grade crossings accepted higher levels of risk, as measured by "unsafe" behaviors, such as failing to wear seat belts and running red lights. Social factors, such as perceived pressure from peers and other drivers, also influenced the likelihood that a driver would exhibit risky behavior. Although drivers were generally more conservative when there were other passengers in the car, there was an exception when both the driver and passenger were males; in this case, the male driver exhibited riskier behavior. Additionally, the behavior of drivers in other vehicles influenced one's risk-taking behavior. For example, drivers of a lead vehicle accepted shorter gap times for entering traffic when there were other cars following or violated a grade crossing because other drivers did.

Age and gender differences moderate driving style. The patterns for rail-highway accidents were similar to those for highway accidents in general such that young and older drivers were involved in more highway and grade crossing accidents than middle-aged drivers, and male drivers were involved in more highway and grade crossing accidents than female drivers.

2.3 Organizational/Management Behavior

To positively impact driver behavior, organizations must have an appropriate view of the driver. A "typical" driver is a rational, but imperfect, decision maker. Decisions are not based solely on the information at the crossing but are also determined by one's perceptions and experiences. Thus, a driver's decision at a grade crossing, derived from a weighting of the costs and benefits of various actions, may differ from that determined by a highway-safety specialist. Consideration of the driver as a reasonable decision maker allows the evaluation of countermeasures in the full context of the driving task, placing less emphasis on countermeasures that are aimed at informing drivers of rules and more emphasis on countermeasures that target the driver's decision making process.

Although Lerner, et al. does not specifically discuss the role organizations and management play in improving grade crossing safety, the authors do note the importance of addressing improvements in grade crossing safety at a systems level rather than on a site-by-site basis. Taking this systems approach will require coordination among local, state, and federal agencies, railroads, and communities to identify which crossings to improve and what those improvements should entail because a change at one grade crossing could have implications for driver behavior at all grade crossings.

For example, improving the credibility of a warning signal at one crossing could foster respect for all active warning signals. In one approach, the public helps identify signal malfunctions so that the problem can be addressed immediately. In the state of Texas, signs are posted at all active crossings on state highways with a toll free number and a crossing number to identify the site. Drivers calling to report a problem speak to the Department of Public Safety who notifies the railroad company. Another approach is to implement constant warning time systems to reduce the waiting time. Shorter waiting times at one crossing may reduce drivers' perception of the waiting time at *all* grade crossings and thereby improve compliance, even at grade crossings without constant warning time systems. Because upgrading technologies at grade crossings is determined on a site-specific basis using a hazard index, a systems-wide view would allow sites to be selected to best enhance driver perception of signal credibility.

Implementation of countermeasures may also require coordination with the appropriate highway agencies. Many standard highway traffic control devices have been proposed for use at grade crossings, and use of these devices may have implications for the general highway driving situation. For example, although drivers tend to comply with stop signs, yield signs, and traffic signals at highway intersections, the results of several studies indicated that drivers do not show the same respect to these devices when they are installed at grade crossings. In these studies, drivers frequently ignored stop signs at crossings and crossed during the red phase when a traffic signal was used. Consequently, there is concern that the use of standard highway traffic control devices at grade crossings may lead to system-wide effects of a general disregard for these devices in other situations. This issue is discussed in more detail in Section 3.1.1.1.

2.4 Environmental context

Lerner, et al. discussed the role of two environmental forces that influence driver behavior: *education* and *enforcement*. With respect to the former, the use of education is often cited as a countermeasure for improving driver understanding of the meaning of crossing-related traffic control devices, the actions required, and the risks at grade crossings. The most widespread education program is Operation Lifesaver, and although it has been credited with declines in grade crossing accidents, no formal evaluation has been conducted. Other suggestions for educating drivers include incorporating material on highway-rail grade crossings in high school driver education curriculums, driver licensing handbooks and exams, and public service activities; targeting specific driver groups, such as older drivers or truck drivers, to highlight the types of accidents in which these driver groups are most frequently involved; and educating drivers about their perceptual limitations. Whereas much interest in developing an education program to improve driver behavior exists, it is important to note that the effects of education are not known. Only a few studies have evaluated the effectiveness of education programs, and these have not found a positive correlation between safe driving behavior and knowledge of a sign's meaning, the action required, accident-risk factors, or the estimated number of fatalities.

With respect to traffic enforcement, grade crossings are rarely patrolled. Enforcement is difficult due to the low frequency of trains at a given crossing. Even though the presence of enforcement at grade crossings improved compliance, this improvement was only temporary. To make better use of enforcement, Lerner, et al. recommended policing crossings at those times of greatest vehicle traffic and train traffic or using automated cameras to record violators. One innovative method is a "trooper on the train" concept in which a police officer, riding on the train, identifies violators and passes their information on to an officer at the crossing who stops the violator. This program allows policing of numerous crossings and is efficient in that drivers are only observed when a train is present. However, the fact that the enforcement is not visible may reduce its impact. At the time Lerner, et al. conducted their literature review, no evaluation of the trooper on the train program had been conducted.

2.5 Summary

The report by Lerner, et al. highlights the issues confronted by drivers when negotiating a grade crossing. Although drivers generally understand the meaning of signs and warning devices at grade crossings, many do not understand the specific action required and fail to appreciate the potential hazards at crossings. Compliance at grade crossings is variable, and failure to comply may result from error or intention. With respect to the former, perceptual limitations may result in missed cues regarding the presence of a crossing or train, particularly at night, or misjudgments in train speed or distance. These limitations are exacerbated by alcohol use, drug use, and fatigue. With respect to the latter, a driver's decision to violate a crossing is the result of a cost-benefit analysis in which factors such as one's expectancies regarding the likelihood of a train, familiarity with the crossing, and perceived credibility of the warning devices are weighed. Of particular concern are drivers who are risk-takers and simply accept higher levels of risk. Social pressure, from either peers or other drivers, increased risk-taking behavior, with young, male drivers being the most susceptible.

Lerner, et al. reviewed a wide range of countermeasures to assist the driver: redesigning the advance warning sign and other warning devices, improving the saliency of the train, improving the credibility of the warning device, better educating the public regarding their risks at grade crossings, and enforcement. In implementing these countermeasures, the use of a systems perspective may be valuable, particularly in determining the extent of their effectiveness.

The Lerner, et al. (1990) report provided the starting point for this literature review. Many of the issues discussed by Lerner, et al. are still relevant to the grade crossing problem, and thus this document discusses similar issues and countermeasures to offer additional insight into driver behavior. Since negotiating a grade crossing is only one aspect of the general driving task, this review addresses the grade crossing problem from a larger perspective by examining driver attitudes in the general driving situation and applying those lessons learned to the grade crossing domain. Additionally, by considering driver behavior in the context of a sociotechnical system, this review will address in more detail than the Lerner, et al. report, the role and influence of organizations and management and the coordination and collaboration that will be required to improve grade crossing safety.

3 Technical/Engineering System

This technical/engineering system component of the sociotechnical model consists of elements of the grade crossing environment and the train. This section addresses the design of warning devices at grade crossings and on the train, and the effectiveness of these devices in influencing driver compliance. It also considers crossing characteristics and attributes of the train that contribute to their detection and recognition by drivers. First, research addressing driver comprehension and compliance to traffic control devices at grade crossings is reviewed and proposed alternatives are discussed. Second, factors affecting detection of the crossing, such as low illumination or physical characteristics of the crossing, are examined. Third, efforts to increase the detection of the train through both visual and auditory means are described.

3.1 Traffic Control Devices

Signs, pavement markings, and active warning devices, such as flashing lights and gates, indicate the presence of a crossing and convey the safe driving actions required. Laboratory studies and field tests have extensively evaluated driver comprehension, detection and compliance with these traffic control devices and have examined alternatives to these devices to determine their effects on driver behavior.

3.1.1 Signs

Although the crossbuck and advance warning sign convey the message that a grade crossing is near, the driver action required and the location of the sign with respect to the grade crossing is not well understood (Bridwell, et al., 1993; Dolan, 1996; Fambro, et al., 1994; Picha, et al., 1997). This section addresses research conducted since the publication of Lerner, et al. (1990) that examined driver understanding of the signs at grade crossings and discusses proposed alternative sign systems to improve driver comprehension.

3.1.1.1 Crossbuck and Advance Warning Signs

Several studies have examined driver attitudes towards grade crossings and driver comprehension of signs at grade crossings. The results generally show that drivers recognize the warning signs (Dolan, 1996; Global Exchange, 1994; Picha, et al., 1997). In one focus group, participants named the advance warning sign as the most familiar indication of a grade crossing followed by the crossbuck and pavement markings (Dolan, 1996), and participants in another focus group indicated that they considered crossbuck to be the basic marker identifying the location of railroad tracks (Global Exchange, 1994).

However, many drivers do not know where the signs are located relative to the grade crossing, that both the advance warning sign and crossbuck are used at active and passive crossings, or what driver action is required. Responses to a questionnaire examining driver understanding of the standard advance warning sign showed that although 81 percent of drivers could identify the sign when shown an image of it, 18 percent of drivers did not know where the sign was located with respect to the crossing (Picha, et al., 1997). Similarly, a survey conducted by Fambro, Schull, Noyce, and Rahman (1997), which tested driver understanding of traffic control devices at grade crossings and their responsibilities, found that 30 percent of the drivers did not know where the advance warning and crossbuck signs were located with respect to the crossing, 50 percent of drivers did not know that the advance warning sign was used at both active and passive crossings, and 34 percent did not know that the crossbuck was used at both crossings.

When asked what action was required at active and passive grade crossings, the majority of drivers (66 percent) noted that they would “stop, look, and listen” for a train at a passive grade crossing; 18 percent indicated they would do so at an active crossing. A follow-on in-vehicle observational study showed, however, that few drivers actually stopped at crossings.

In the study, an in-vehicle observer guided 30 drivers along a course containing active and passive grade crossings and recorded the driver’s looking behavior and deceleration behavior on the approach to each crossing. Observations indicated that the majority of drivers did not slow down or stop when approaching a grade crossing. Even at a stop-sign controlled passive crossing, 10 percent of drivers slowed on the approach but did not stop, and 33 percent of the drivers came to a rolling stop. Drivers decelerated at grade crossings primarily out of concern for the perceived roughness of the grade crossing surface rather than their responsibility for ensuring crossing safety. Additionally, drivers did not always look both ways at crossings. Looking behavior was greater at passive crossings than at active crossings, but at one passive crossing with a low-train volume, more than half the drivers failed to look in either direction.

As part of a larger study to improve the traffic control devices at passive grade crossings, Lerner, et al. (2002) conducted focus groups to understand driver beliefs, perceptions, and expectancies at grade crossings and of traffic control devices. Participants were drawn from two regions: one with relatively few grade crossings, most of which had active traffic control devices, and one from a rural area with many grade crossings, including a number of passive crossings. In the focus group, each participant was given a sheet with a plan-view diagram of a two-lane roadway with a grade crossing and asked to draw the signs and markings present at a typical crossing. Examination of the drawings showed that most of the participants lacked an accurate understanding of how traffic control devices were used. Only one out of the 23 participants drew a diagram that resembled actual practice. The crossbuck was drawn by only five of 23 participants, suggesting that drivers forgot or ignored them. Twenty of 23 participants included an active traffic control device or some indication to stop, suggesting that drivers expected an explicit indication of the behavior required at the crossing and that they believed that they must stop and look at the crossing although, as noted in the study by Fambro, et al (1997), few actually did so.

After participants completed the drawing, they discussed the use of the advance warning sign and crossbuck, the driver actions required, their location, and their effectiveness. Similar to the findings of previous studies, the discussion showed that drivers generally did not understand the message and use of the standard crossbuck. Participants thought the crossbuck was used solely to mark the location of the railroad tracks, and some thought that it required drivers to “stop, look, and listen.” Additionally, many participants did not realize the crossbuck was present at all grade crossings or even that it was widely used. In fact, some participants thought the crossbuck was used only in rural locations or on back roads. Thus, the results of the focus groups highlighted that the current sign systems used at grade crossing is not well understood and that drivers expect, and want, more information than is currently provided.

Alternative Sign Systems

Driver understanding of the crossbuck and advance warning sign have been evaluated with alternative signs to improve methods for communicating driver requirements at active and passive grade crossings. In particular, the presentation of supplementary signs for use in conjunction with the standard advance warning sign and crossbuck has received much interest. Picha, et al. (1997) evaluated driver understanding for the standard advance warning sign when it was presented alone and with a supplementary plaque stating “500 ft.” Two additional alternative sign systems for conveying the presence of a crossing were also evaluated as part of the study: a circular sign with an image of a black locomotive, and a circular sign with an image of a black locomotive with the text “500 ft” below the image. Participants completed a survey in which they were shown images of signs and asked to select the correct response. As reported above, the majority of participants recognized the standard advance warning sign. Additionally, their comprehension of its meaning and their knowledge of its location was significantly improved when it was presented with the supplementary plaque that indicated the distance to the crossing. The two signs that showed the image of the train were not as well understood as the standard advance warning sign.

The similarities between driver actions at a grade crossing and that at a highway intersection have prompted particular interest in the use of stop and yield signs at grade crossings intersections. The general belief is that these two signs are easily understood by drivers and thus may result in more desirable behavior. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) required that the FHWA revise the MUTCD to allow state and local governments to use stop or yield signs at passive grade crossings where two or more trains operated daily. A joint memorandum from the FHWA and the FRA contained additional guidance for the use of these signs. In particular, the document recommended that two considerations be met when using the stop sign:

(1) State and/or local police should commit to a program of enforcement for stop sign-controlled grade crossings as rigorously as they would a stop-sign controlled highway intersection, and

(2) Use of the stop sign should not create a riskier condition (considering the likelihood and severity of traffic risks and highway-rail collisions) than that existing with use of a yield sign.

Additionally, the memorandum listed several crossing characteristics where the use of a stop sign could reduce the accident risk:

- Crossings where the maximum train speed was greater than or equal to 30 miles per hour (mph) (48 kilometers per hour (km/h)),
- Crossings where the highway traffic mix consisted of buses, hazardous materials carriers, and/or large equipment,
- Crossings with train movements of 10 or more per day on five or more days per week,
- Crossings with rail lines used by passenger trains,
- Crossings where the rail line is used to regularly transports significant quantities of hazardous materials,
- Crossings where the highway meets two or more tracks, and in particular, where both tracks are main tracks or one track is a passing siding that is frequently used.,
- Crossings with a skewed angle of approach, and
- Crossings with a restricted line of sight such that approaching traffic must substantially reduce its speed.

The memorandum noted that these conditions should be weighed against the existence of a highway that is not secondary in character (i.e., where the annual daily traffic is 400 in rural areas and 1,500 in urban areas) or at crossings where a steep ascending grade occurs on the approach to or through the crossing, unrestricted sight distance in relation to maximum crossing speed, and used by heavy vehicles (FHWA, 2002).

In 1998, the National Transportation Safety Board (NTSB) examined safety at passive grade crossings and recommended the use of stop signs at all passive grade crossings because the presence of the stop sign provides consistent information and requires a response by the driver that is well understood (NTSB, 1998). The use of stop signs at grade crossings is controversial, and the recommendation by the NTSB to equip all passive grade crossings with stop signs has been widely criticized. Lerner, et al. (1990) noted that although the use of stop signs reduced approach speed and increased looking behavior, actual rates of compliance with stop signs at grade crossings were lower than at roadway intersections. In fact, results of observational studies suggested that drivers made a distinction between stop signs used at highway intersections and those at grade crossings and failed to comply with stop signs at crossings. More recent studies have reported similar results. Burnham (1995) observed driver behavior at seven grade crossings equipped with stop signs for traffic control and found that only 18 percent of drivers came to a full stop at the crossing. Fifty percent of drivers slowed to a roll or stopped on the tracks, and 32 percent did not stop at all. Furthermore, the percentage of drivers stopping at sites with limited sight distance was low. Similarly, in an analysis of 60 passive grade crossing accidents by the NTSB, 22 of the accidents occurred at intersections protected by a stop sign, and in half of these accidents, the drivers made no attempt to stop (NTSB, 1998). Although this noncompliance may be the result of a lack of enforcement at grade crossings (this issue will be discussed in more detail in Section 6.3), concern that noncompliance at grade crossing stop signs could foster a general disrespect for the stop sign and carry over to nongrade crossing situations is prevalent (Lerner, et al., 2002). Additionally, uncertainty about whether a driver will comply with the stop sign at the grade crossing could affect the potential for rear-end collisions and other non-train related collisions (Burnham, 1994; Lerner, et al., 2002).

In addition to the problem of low compliance, two other concerns have been noted with respect to the use of stop signs at grade crossings. First, stopping at the crossing may hinder the driver's ability to judge the speed of an approaching train. As noted in Lerner, et al. (1990), drivers have difficulty estimating approaching train speed at a distance away from the crossing where the lateral movement of the train provides cues regarding the train's arrival time at the crossing. These cues are not available when the driver is stopped at the crossing, and the driver must rely on the rate of apparent change in the train's size. Consequently, drivers, stopped at the crossing, may believe that they have enough time to start and clear the crossing before the train's arrival. Second, drivers of large trucks will require more time to clear the crossing if a stop is required than if they cross the tracks at a slow roll. While acknowledging these concerns, the NTSB believed that the safety benefits gained outweighed the costs. A stop sign clearly conveys the action required, a driver stopped at the crossing will have more time to look for a train, and there is usually adequate sight distance along the tracks when viewed from the stop line (NTSB, 1998).

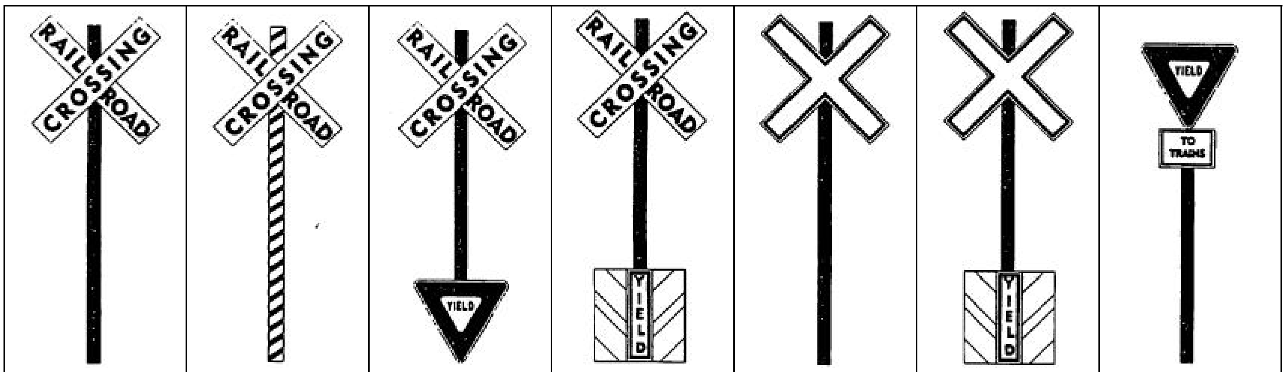
The results of a recent accident analysis suggest that the installation of stop signs may not increase safety at grade crossings, however, and in fact raises questions regarding its use. Raub (2006) analyzed collision data for 10 years from 1994 through 2003 for seven Midwestern states, using information from the FRA accident/incident database. The analysis examined the annual rate of collisions and casualties (defined as a combination of injuries and fatalities) as a function of the warning device at the crossing: crossbucks, stop signs, flashing lights, or gates. Other warning systems (e.g., no device, traffic signals, and flagmen) were excluded from the analysis because they were used at few crossings (7 percent) and accounted for less than 3 percent of crashes. A comparison of crash rate per 100 million of crossing vehicles (MCV; calculated as the sum of the average daily traffic at the crossing divided by 1 million), crash rates per 1 million annual trains, and exposure level (calculated as a product of the average daily traffic and crossing trains) all showed that the likelihood of a collision at stop sign controlled grade crossings was higher than that at crossings protected by other warning systems. Crossings with stop signs had a crash rate of 4.76 per 100 MCV, a rate 1.5 times greater than that for crossings with crossbucks (1.87 per 100 MCV), and over 7 times greater than that at active crossings (0.59 per 100 MCV for flashing lights and 0.71 per 100 MCV for gates). The crash rate per 1 million annual trains at stop sign controlled crossings was 2.93 per 1 million trains, a rate 25 percent higher than that at crossbuck-only crossings (2.21 per 1 million trains). Crossings with flashing lights had a crash rate of 2.75 per 1 million trains, and crossings with gates had a crash rate of 1.14 per 1 million trains. Finally, a comparison of the exposure level showed that crossings with stop signs had an exposure level 9 times higher than that at crossbuck-only crossings, 18 times higher than at flashing light crossings, and 31 times higher than at gated crossings. Raub also conducted an analysis examining the crash rate at stop sign controlled crossings before and after the protection at the crossing changed from crossbucks to stop signs, or vice versa. The results of this analysis showed that crash rates increased slightly when stop signs replaced crossbucks, but this difference was not significant due to the low sample size; there were only 1,939 crossings in this analysis, and collisions at only 175 of the crossings. Nevertheless, the finding suggests that the use of stop signs at grade crossings may not have the hoped for improvements to safety.

Raub hypothesized that the high crash rates for the stop sign relative to other warning devices may reflect a pattern of noncompliance with the stop sign when it is used at low-volume traffic intersections, as reported by Mounce (1981). In that study, Mounce observed driver violations and compliance at stop sign-controlled traffic intersections as a function of traffic volume and found that there was a correlation between the two. Compliance with the stop sign decreased as traffic volume decreased from a rate of 5,000 – 6,000 average daily traffic to below 2,000 in average daily traffic. This noncompliance was attributed to a lack of respect for the stop sign, resulting from its overuse for controlling traffic, particularly at intersections where stop sign control might not be needed (e.g., at low volume intersections). Consequently, drivers see stop signs at intersections where they can easily see that there is little cross traffic and that the potential for conflict is low and begin treating these stop signs as yield control. In fact, Lum and Stockton (1982) found that fewer drivers stopped or slowed below 5 mph at intersections controlled by stop signs than at intersections controlled by yield signs. Furthermore, an examination of accident rates showed more accidents at stop sign-controlled than at intersections with yield signs or no signs at all.

The results suggest that other passive warning devices may be more effective than presenting stop signs at grade crossings and that particular consideration should be given to the use of the yield sign. In fact, the MUTCD allows the choice of using a stop or yield sign in conjunction with the crossbuck at all highway approaches to passive grade crossings (FHWA, 2003). Given the concern that indiscriminate use of the stop sign at all or many passive grade crossings could lead to noncompliance, on March 17, 2006, FHWA issued a memorandum clarifying their position on the MUTCD provision by recommending yield signs be considered the default traffic control choice at passive crossings, unless an engineering study or judgment indicated that a stop sign would be more appropriate. Thus, the use of a stop sign at passive crossings is limited to unusual conditions.

Most drivers do not associate the action to yield with the crossbuck sign (Lerner, et al., 2002), so incorporating the yield message into the sign system may be beneficial. Although yield signs are not used frequently at grade crossings, several studies have examined the effectiveness of the standard yield sign or evaluated the effectiveness of sign systems that incorporate the "yield" message with the crossbuck. Bridwell, et al. (1993) evaluated the comprehension of the standard crossbuck to six alternative sign systems (shown in Figure 3), four of which presented an explicit message to "yield":

- Standard crossbuck on a "barber striped" pole,
- Standard crossbuck with a standard yield sign (R1-2) mounted below,
- Standard crossbuck with Conrail yield sign mounted below. The Conrail sign is a three-paneled sign with "yield" written vertically on the front panel in red letters on a silver background and two side panels with alternating red and silver diagonal stripes bent backwards at 45-degree angles,
- Modified Canadian crossbuck, a white X-shaped sign with a red border,
- Modified Canadian crossbuck with the Conrail yield sign mounted below, and
- "Yield to Trains": Standard yield sign with a regulatory plaque below reading "TO TRAINS"



Standard crossbuck	Standard barber	Standard yield	Standard Conrail	Canadian crossbuck	Canadian Conrail	Yield to trains

Figure 3. Sign systems evaluated by Bridwell, et al. (1993).
Note: the bottom 12" (30 cm) of the poles was not shown.

Participants were shown images of each of the seven signs and asked to provide its meaning and required action. If the participant's initial response was unrelated to grade crossings, the participant was provided with context information and shown an advance crossing sign, and asked whether seeing that sign before the test sign would change the response. The results showed that the meaning of the standard crossbuck sign and the test signs that included the standard crossbuck were identified with perfect accuracy without requiring any additional context. The Canadian crossbuck and the "Yield to Trains" sign required context but once participants saw the advance warning sign they understood their meaning with perfect accuracy. Comprehension of driver action was highest for the standard crossbuck with the yield sign and

"Yield to Trains" sign, regardless of whether participants saw the advance crossing sign. Driver action was least understood for the standard crossbuck and Canadian crossbuck. Thus, the results showed that the standard crossbuck used in conjunction with the yield sign was best understood for both meaning and required action and highlighted the fact that the standard crossbuck, when used alone, did not effectively convey the required action.

Russell and Kent (1993) addressed the effectiveness of the standard yield sign on short-and long-term driving behavior as part of a larger effort to evaluate the use of low-cost traffic control systems for passive grade crossings. They evaluated five prototype systems:

System 1: A crossbuck with a Conrail shield attached to crossbuck post below the crossbuck

System 2: A delineator system presenting roadside reflectors between the advance warning sign and the crossbuck. A standard crossbuck was presented at the crossing, and high-intensity retroreflective tape was placed on the front and backsides of the crossbuck posts,

System 3: A highway yield sign at the crossing with a "Yield Ahead" sign on the approach to the crossing,

System 4: A combination of Conrail shield and delineators (i.e., Systems 1 and 2), and

System 5: A combination of Conrail shield, delineators, and yield sign with a "Yield Ahead" sign on approach (i.e., Systems 1, 2, and 3).

Each system was installed at one passive grade crossing in Kansas, with the delineator system installed at two crossings. Comparisons of drivers' deceleration rate, distance of brake application, and looking behavior before and after the system installations served as measures of driver behavior. Data collection in the "after" phase occurred in two time periods: two months after the installation to determine the short-term effects of the systems on driver behavior, and seven months after the installation to determine if more long-term, permanent changes occurred.

Of the five systems tested, only the delineator system (System 2) showed any long-term improvements in driver behavior, particularly in terms of deceleration rate and looking behavior. The use of the standard yield sign (System 3) showed slight improvements in the short term, as exhibited by increased deceleration rate and braking percentage, but braking percentage actually decreased over the long-term. Of more concern was the fact that looking behavior showed significant decreases in both the short- and long-term, suggesting that the yield sign could negatively affect driving behavior. The results for the Conrail shield system (System 1) showed increased deceleration rates, increased braking at night, and increased looking behavior in the short-term, but observations of driver behavior 7 months after installation showed only increased deceleration rates. Combining the devices (as in System 4 and 5) did not result in increased benefits. In fact, the combination of the Conrail shield, delineators, and the standard yield sign showed no significant long-term improvements and may simply have created more visual clutter near the crossing. Whereas the results did not show significant benefits for the use of the yield sign, the authors noted that the data collected was limited in scope and size and consequently, urged caution in concluding that systems that did not show positive long-term results were not effective.

Several studies conducted by the Texas Transportation Institute addressed the effectiveness of incorporating the "yield" message into sign systems at passive grade crossings (Fambro, Beitler, and Hubbard, 1994; Fambro, et al., 1997; Fambro, Schull, Noyce, and Rahman, 1998; Noyce and

Fambro, 1998). In the first study, Fambro, Beitler, and Hubbard (1994) measured and compared driver behavior and opinions of the standard advance warning sign and crossbuck sign system to three experimental sign systems:

1. The railroad advance warning sign presented with a modified Canadian crossbuck,
2. Two advance warning signs on the approach to the crossing (the standard advance warning sign and a diamond shaped yellow sign showing a black train symbol with a supplementary plaque reading “Look for Trains”) and a modified Canadian crossbuck and the standard yield sign presented with a “to trains” advisory plate presented at the crossing, and
3. Same as sign system 2, except the standard crossbuck was presented at the crossing rather than the Canadian crossbuck.

Participants drove through a test course that contained the current sign system with the standard advance warning sign and crossbuck and the three experimental systems. An in-vehicle observer collected objective and subjective data. Objective measures consisted of participants’ approach speeds to the crossings and their looking behavior. Subjective measures included participants’ opinions on the signs and rankings of their effectiveness.

The results showed no difference in approach speed to the crossing between the current sign system and the experimental sign systems. Although the data on looking behavior showed that drivers looked more at the experimental sign systems than at the current sign system, it was not clear if this was attributable to the experimental sign systems themselves, to a novelty effect, or to sampling differences between the test groups. Subjective rankings of the sign systems showed that participants considered the experimental sign systems that provided explicit instructions (e.g., “Look for Trains” or “Yield to Trains”) to be more effective than the standard sign system. However, similar to the comprehension results reported above by Bridwell, et al. (1993), not all participants understood the meaning of the Canadian crossbuck.

The “Look for Trains” and “Yield to Trains” signs were further evaluated in a field study conducted at eight passive grade crossings in Texas (Fambro, Beitler, and Hubbard, 1994; Fambro, Schull, Noyce, and Rahman, 1998). The “Look for Trains” sign was placed at the start of the pavement marking for the crossing, and the standard yield sign with a “to trains” message plate was installed next to the crossbuck. Observers at the crossings measured drivers’ approach speed and looking behavior. Observers stationed beyond the crossing stopped drivers after they had passed the crossing and asked questions to determine drivers’ understanding of and attitudes towards the sign system.

The results of the field study showed that the effectiveness of the sign system varied by crossing. Observers noted reduced approach speeds and increased looking behavior at some but not all of the crossing locations. The presentation of the “Yield to Trains” sign decreased approach speeds at two of six sites and increased looking behavior at three of eight sites. The use of the “Look for Trains” sign decreased approach speeds at one of the two sites at which speed data was collected and increased looking behavior at one of four sites. Although the overall effectiveness of the two supplementary signs on looking behavior and approach speed was not clear, the authors stressed that the implementation of the signs did not have negative effects. Neither sign caused an increase in approach speed or a decrease in looking behavior. Driver feedback was positive for the two signs; a significant proportion of drivers noticed the new warning signs and felt that their use could improve crossing safety.

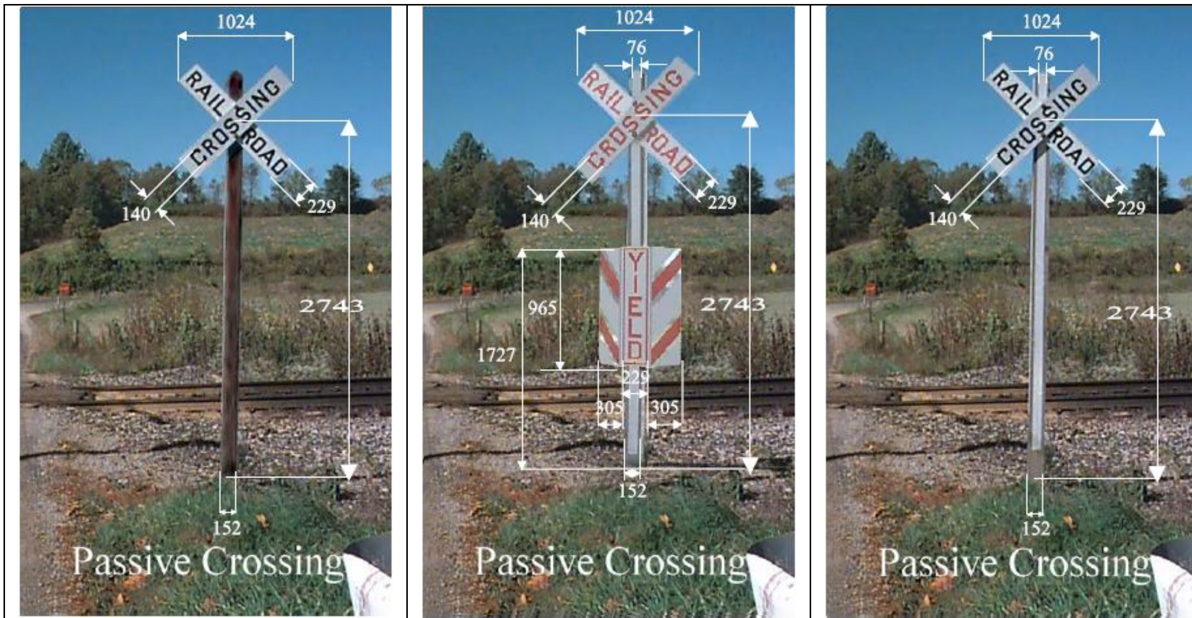
Collectively, the results of studies addressing the use of the standard yield sign or sign systems incorporating the “yield” message with the crossbuck showed improved driver comprehension regarding the action required over the crossbuck alone, but the results of field data were mixed. The series of studies conducted by the Texas Transportation Institute indicated driver preference for sign systems that incorporated the “yield” message, but objective results of field evaluations were inconclusive regarding its effect on looking behavior or approach speed (Fambro, et al, 1994, 1997, 1998; Noyce and Fambro, 1998). Of particular concern were the results reported by Russell and Kent (1993), which found a *negative* effect on looking behavior when a standard yield sign was used. It is also possible that the standard yield sign does not receive the level of respect drivers have for the stop sign in the highway driving situation, an attitude that could influence driver’s compliance with the yield sign at grade crossings. Thus, additional studies are needed to evaluate the use of the yield sign and examine how best to incorporate the message to improve driver behavior in the long term.

Conspicuity

Particular attention has been given to enhancing the conspicuity of the crossbuck. In the study conducted by Bridwell, et al (1993), described above, the standard crossbuck had the lowest conspicuity level of the sign systems evaluated. As part of the study, participants completed a recognition distance and conspicuity task. In the recognition distance task, participants saw slides of each of the sign systems (shown in Figure 3) at incremental sizes and responded as soon as the sign could be described. A computer-controlled zoom lens projected the sign systems, presenting each sign system initially at a small size and then gradually increasing its size to make it appear as if one were approaching in a vehicle. In the conspicuity task, the number of times a test system was identified accurately after only a brief presentation (i.e., 2 seconds) was measured. Participants saw a test slide containing nine signs presented in a 3x3 matrix. After the test slide, a slide showing an empty 3x3 matrix with an arrow pointing to one of the three rows appeared, and participants identified the signs shown in the selected row. The signs in the task included six of the seven test sign systems (the “Yield to Trains” sign was excluded) and 48 signs from the MUTCD. Accuracy for a sign system was defined to be the number of times it was correctly identified when presented within the matrix of nine signs. The results showed no differences in recognition distance among the seven signs but found that the standard crossbuck presented with the standard yield sign, the standard crossbuck on the barber-striped pole, and the Canadian crossbuck with the Conrail shield had the highest conspicuity scores.

Reflectorization is a simple, low-cost method for improving conspicuity. Many experimental sign systems discussed previously incorporated reflectorization, although the benefits of reflectorization alone were not the focus. The use of reflectorization in the sign systems evaluated by Russell and Kent (1993), described above, contributed to a high visual impact; the reflectorized crossbuck presented with delineators resulted in the most improvements in driver looking behavior and deceleration rate.

Zwahlen and Schnell (2000) compared the effectiveness of the standard crossbuck to two reflectorized crossbuck systems: a standard improved crossbuck and the Buckeye crossbuck. The crossbuck systems are shown in Figure 4.



(a) Standard Crossbuck | (b) Buckeye Crossbuck | (c) Standard Improved Crossbuck

Figure 4. Crossbuck systems used in Zwahlen and Schnell (2000).
Dimensions shown are in mm.

The standard improved crossbuck was similar to the standard crossbuck except reflectorization was added on its blades and the wooden crossbuck post. The Buckeye crossbuck consisted of a crossbuck presented in conjunction with an improved version of the Conrail shield. The crossbuck in the Buckeye crossbuck contained the words “Railroad Crossing” written in red letters on a silver background, and the shield incorporated the “yield” message and was illuminated with high performance reflective material along all its sides and along the crossbuck post.

A before and after study was conducted along four rail corridors in Ohio. Video data provided information on driver compliance, as measured by the number of near collisions and violations. In the “before” part of the study, all the crossings were equipped with the standard crossbuck. In the “after” part of the study, half the crossings were equipped with the standard improved crossbuck and the other half with the Buckeye crossbuck. Although the overall results showed no differences in driver compliance, data examining time-to-collision, defined to be the time between a non-compliant vehicle crossing the tracks and the train’s arrival at the crossing, showed that the standard improved and Buckeye crossbucks had a 5 second greater time-to-collision rate (median time 20 seconds) than the standard crossbuck. Zwahlen and Schnell suggested that the higher time-to-collision rates for the experimental systems could be attributable to the greater conspicuity of the new crossbuck designs. Not surprisingly, luminance measures of the standard improved crossbuck and Buckeye crossbuck showed that both had higher luminances than the current crossbuck because of the incorporation of the reflective markings.

The three crossbuck systems were further evaluated using an accident analysis and user acceptance questionnaire. In the accident analysis, a comparison of crash data for the past 10 years showed a significant benefit for the use of the Buckeye crossbuck in reducing the daytime and nighttime accident rates relative to the standard crossbuck. The results showed no difference between the use of the standard improved crossbuck and the standard crossbuck. In the user acceptance questionnaire, Ohio residents, school bus drivers, delivery drivers, and law enforcement officials indicated their subjective preference for the three crossbuck systems. The questionnaire presented respondents with color pictures of the three crossbuck designs, taken during the daytime, and respondents indicated which one of the designs was preferred. The questionnaire results showed a preference for the Buckeye crossbuck over the standard improved crossbuck. Participants particularly liked the addition of the Conrail shield as they felt it increased the saliency of the sign.

Sign conspicuity is influenced by the location and pattern with which reflective sheeting is applied. Brich (1995) found that the use of reflective sheeting applied to the full length of both sides of the crossbuck posts, plus double-sided crossbucks with high intensity sheeting, would be most conspicuous at grade crossings. Brich evaluated five reflectorized systems, which varied according to five characteristics:

- The crossbuck sign presented (the existing standard crossbuck or a double-sided, reflectorized crossbuck),
- The type of reflective sheeting used,
- The location of the sheeting on the crossbuck (i.e., whether the sheeting was applied to the crossbuck blades or not),
- The length of the sheeting on the crossbuck post (on the back only or on the front and back), and
- The location of the sheeting on the crossbuck post (at or near ground level to center of crossbuck mounting, one foot above the track, or three feet above ground level).

Participants saw photographs of each sign configuration, installed at a passive crossing, and rated the visibility of each sign configuration. The photographs showed the signs at night illuminated by a vehicle's low and high beams. Participants also watched a videotape, which showed the sign configuration as a train passed through the crossing. After viewing the videotape, participants ranked the configurations from best to worst.

Participants gave the highest visibility ratings to the sign configuration with fully reflectorized posts and double-sided crossbucks with reflective sheeting. Participants' comments indicated that the fully reflectorized posts allowed them to see where the roadway met the railroad tracks, whereas reflectorizing only part of the crossbuck post resulted in the perception that the crossbucks were floating. Because participants viewed the images passively (i.e., they did not need to actively navigate the crossing), the results do not relate the impact of this perception on the driving task. Additionally, participants reported seeing a strobe-light effect, created by the reflection of vehicle headlights off the backs of the reflectorized crossbucks when a train was passing through the crossing. This strobe-light effect could help drivers approaching the crossing determine the presence of a train. Thus, to optimize the use of reflectorization, the MUTCD requires that the crossbuck and crossbuck post be reflectorized and that reflective sheeting be applied on the front and back along the full length of the crossbuck posts (FHWA, 2003).

In addition to reflectorization, simply lowering the height of the crossbuck sign may enhance the conspicuity of the crossbuck (Russell, 2002; Russell and Rys, 1997). The MUTCD recommends that the crossbuck be installed so that the center of the sign is 9 feet (ft) (2.8 meters (m)) above the ground, with allowable deviations based on local conditions (FHWA, 2003). However, the results of an examination of headlight illumination from a typical vehicle distributed along a standard crossbuck sign at its current height showed that the maximum illumination was at the base of the crossbuck post. Lowering the crossbuck by 2 ft (0.61 m) would significantly increase the sign illuminance. In fact, the current height of the crossbuck may limit the benefits of reflectorization. Zwahlen and Schnell (1999) noted that luminance measurements indicated that reflectorizing the crossbuck blades was not as effective at short distances because of the height of the blades. The use of the Buckeye crossbuck, which presents a Buckeye shield 3.2 ft (1 m) from the ground, provided for a much higher light return than the blades.

3.1.1.2 Distinguishing Active from Passive Crossings

Every review of grade crossing traffic control devices has criticized the use of presenting the same advance warning sign at both active and passive crossings (Westat, 1999). One problem is that drivers do not realize that the advance warning sign and crossbuck are used at both active and passive crossings (e.g., Fambro, et al., 1997; Lerner, et al., 1990, 2002). A number of countries use distinct advance warning signs that inform the driver that a passive crossing is ahead, but there is no common standard (Small, George, and Roop, 1998). No evidence is available that one design is superior to another, and no study shows the effectiveness of discriminating active versus passive crossings relative to current U.S. practice.

Wigglesworth (2001) hypothesized that drivers' failure to distinguish between active and passive crossings was attributable to the use of the same signage for different procedures. In order to test this hypothesis, he observed driver looking behavior at grade crossings in Australia. In one study, observers collected data on the looking behavior of 92 drivers from unmarked cars at one active and one passive grade crossing, spaced 1,640 ft (500 m) apart. If drivers distinguished between the two, then they would make few head movements at the active crossing but look both ways at the passive crossing. Instead, the results showed that 57 percent of drivers made identical head movements at both crossings; 37 percent made no head movements at either crossing, 4 percent looked one way, and 15 percent looked both ways. In a second study, observers noted the looking behavior of 264 drivers at active and passive crossings from two marked police cars. Although it was expected that the possibility of enforcement would encourage looking behavior at passive crossings, the results showed that 44 percent of drivers made identical head movements at both active and passive crossings. Eleven percent of drivers looked in both directions, 10 percent looked in only one direction, and 44 percent did not look in either direction.

Lerner, et al. (2002) identified four information requirements needed by the driver at a passive grade crossing:

(1) Information that a grade crossing is ahead,

(2) Information that the crossing is a passive crossing and therefore that the driver is responsible for determining if a train is approaching,

(3) Information regarding the actions required at the crossing,

(4) Information regarding whether the crossing has any special conditions, such as limited sight distance.

To convey these requirements, Lerner, et al. developed a comprehensive set of 28 alternative sign concepts from candidate sign systems in existing literature, published studies, signs in use, proposed signs, and the results of the focus group on drivers' understandings of grade crossings and traffic control devices (discussed above). The concepts consisted of 12 advance warning signs at passive crossings (shown below in Figure 5), 7 advance warning signs at active crossings (shown in Figure 6), and 10 crossing signs for passive crossings (shown in Figure 7).

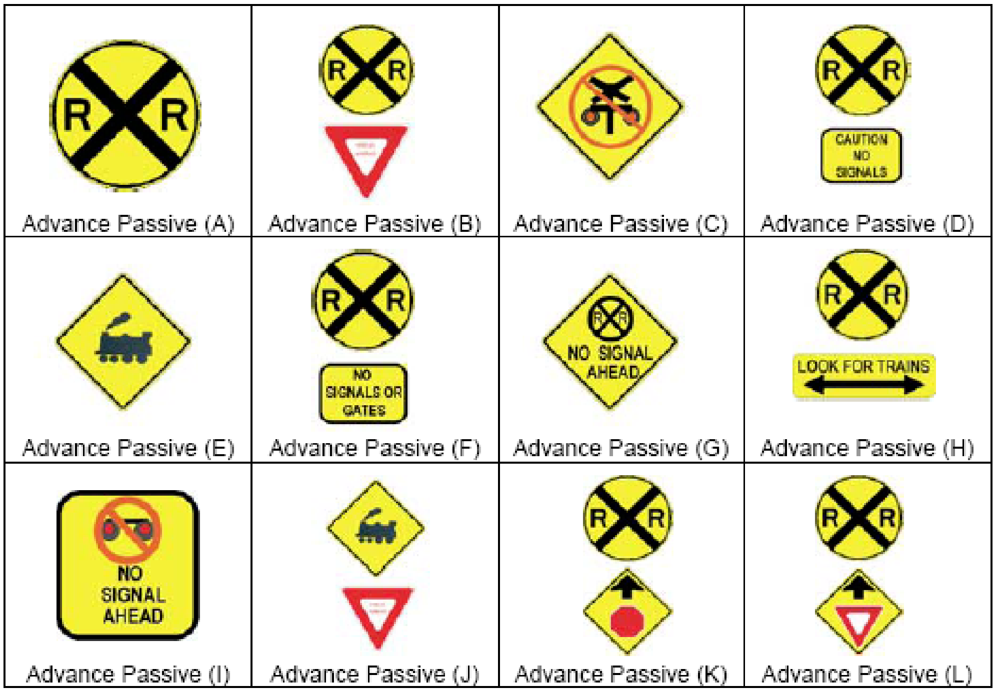


Figure 5. Advance warning signs for passive crossings.

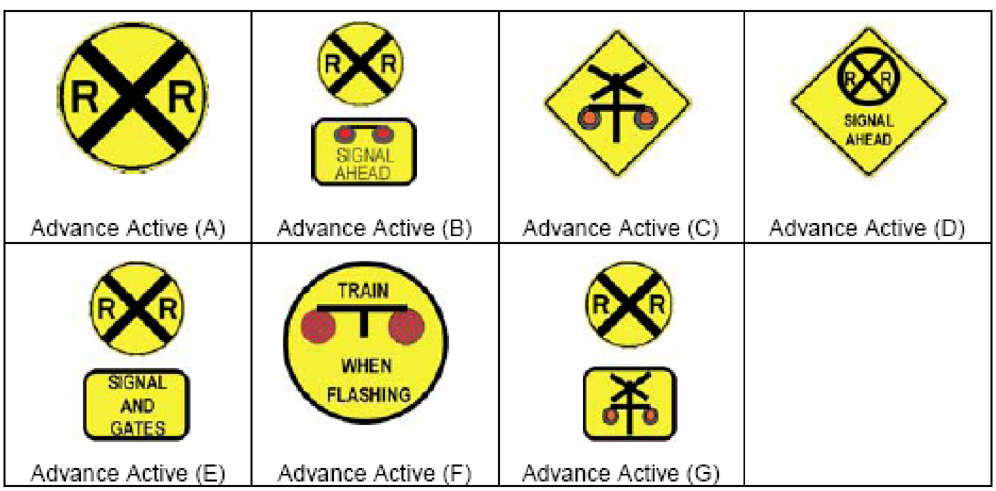


Figure 6. Advance warning signs for active crossings.

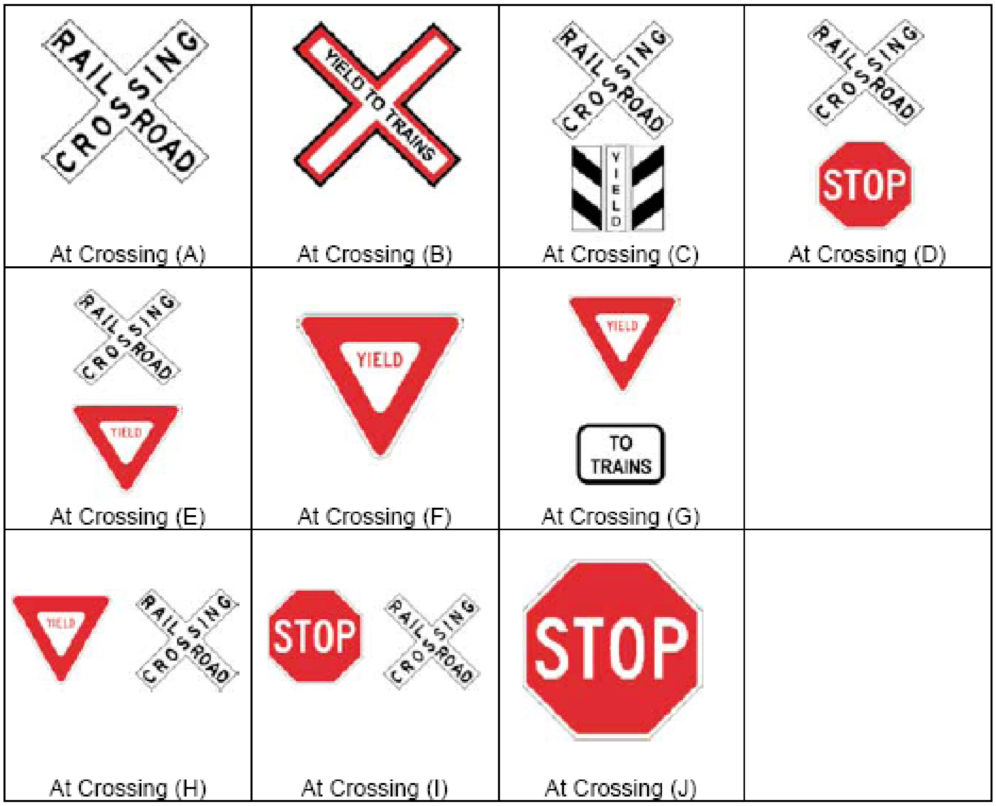


Figure 7. Signs for passive crossings.

The alternative sign systems were presented in a test booklet, with each of the prototype signs shown twice on a page by itself, once in a highway context and once without context. Participants completed both a comprehension task and preference-and-opinion task. In the comprehension task, participants indicated the meaning of the sign and the action required. In the preference-and-opinion task, participants, presented with subsets of the prototype signs grouped by their intended purpose, ranked the prototype signs in each subset in order of preference.

The comprehension results for the prototype signs for passive crossings, shown in Figure 5 above, indicated that the current advance warning sign (Figure 5, sign A) was not well understood, and in fact, could lead to dangerous behavior because some participants assumed the sign indicated a crossing with active protection. Not surprisingly, test sign configurations that included a yield icon most frequently conveyed the requirement to yield at a passive crossing (Figure 5, signs B, J, and L). The results for the preference-and-opinion section showed that participants preferred those signs that presented the standard advance warning sign in conjunction with a word or regulatory-sign-ahead supplementary panel (signs B, D, F, G, H, K, and L, Figure 5) and considered these signs to be most informative and instructive.

Figure 6 above shows the prototype signs for active crossings. Comprehension results for these signs indicated that all the test signs conveyed the message that a grade crossing was ahead, that the crossing had some indication when a train was approaching, and that the driver should look for signals and/or gates and be prepared to stop if activated. Similar to the comprehension results for the prototype passive crossing signs, participants did not understand the meaning of standard advance warning sign (Figure 6, sign A) as well as the test signs and preferred the standard advance warning sign less than the other test signs. Again, the results for the preference-and-opinion section showed that participants preferred test signs that presented the standard advance warning sign with supplementary information (Figure 6, signs B, E, and G). The two supplementary panel signs with text (Figure 6, signs B and E) were preferred over the graphic only version (Figure 6, sign G).

The comprehension results for prototype signs indicating a passive crossing (presented above in Figure 7) indicated the standard crossbuck (Figure 7, sign A) was generally understood to convey the concept of a grade crossing but was not well understood beyond that. When used alone, participants felt that the crossbuck did not convey enough information and did not indicate the required action. Participants preferred the use of a crossbuck in conjunction with a stop or yield sign (Figure 7, signs D, E, H, and I) and commented that these signs were instructive, informative, easy to see, conspicuous, and attention getting.

The results of Lerner, et al. (2002) highlighted the fact that the standard advance warning sign and crossbuck, when presented alone, did not fully convey the intended message. The results did not identify any one icon that clearly indicated the presence of a passive crossing; participants' ratings showed low preference for the use of the crossbuck alone or the use of regulatory signs alone at passive crossings. However, the combination of these signs (i.e., the combination of the standard advance warning sign and crossbuck with text or graphics) was more instructive, improving comprehension of driver action, and preferred by participants over the presentation of the signs alone.

3.1.1.3 Providing other information

Other advance warning signs have been proposed to notify the driver of crossing characteristics, such as limited sight distance, crossing angle, and location. One concept receiving considerable attention is a sign that alerts drivers and pedestrians to the possibility of a second approaching train at a grade crossing (PB Farradyne, Inc., 2002; Sabra, Wang, and Associates, 2002). Drivers and pedestrians at grade crossings with multiple tracks may think they are acting safely by cross the tracks when they see one train stopped at a station or approaching from a considerable distance and may not realize that there is a second train in the vicinity approaching from the opposite direction. The Baltimore Central Rail Line developed and evaluated the use of a prototype sign system to inform drivers of an approaching second train. The prototype system consisted of a dynamic display that started by flashing the text message "Warning" for 2.5 seconds, followed by a steady text message "2nd Train Coming" displayed for 2.5 seconds, and concluded with an animation of two trains approaching from opposite directions, one on each of two tracks, at a highway-rail intersection. Installation of the prototype system occurred at one busy highway-rail grade crossing in Maryland, and observations noted changes in "risky" driver and pedestrian behavior from before the installation of the system to one month after installation and then again two months after installation. Measurements of "risky" behavior consisted of the number of pedestrians and drivers that crossed in front of lowered gates, the number of drivers that tried to proceed after the first train passed but then stopped after realizing a second train was approaching, and the number of cars that cleared the tracks after the first light rail vehicle cleared the crossing while the gates were ascending and before the gates descended again for the second light rail vehicle. Risky behavior dropped by 80 percent two months after installation of the prototype system. Of note was the fact that the number of vehicles that crossed the tracks in between the first and second trains decreased by 26 percent. A driver survey, conducted to determine subjective opinion on the effectiveness of the sign, indicated that most drivers felt the sign increased awareness at the crossing (Sabra, Wang, and Associates, 2002).

The Los Angeles County Metropolitan Transit Authority developed and evaluated a similar sign system concept but focused primarily on improving pedestrian safety (PB Farradyne, Inc., 2002). Their prototype second train warning sign consisted of two static images. The first showed a pedestrian watching one light rail vehicle approach on a track from the right; the second showed a pedestrian watching a second light rail vehicle approach on a second track from the left. Observation of pedestrian behavior before and after the installation of the prototype sign system showed benefits for the use of the prototype sign. The number of pedestrians crossing the tracks within six seconds of an approaching train decreased by 32 percent after the sign was installed. However, the meaning of the sign was not intuitive; only 4 percent of pedestrians understood the sign's meaning that two trains were at the crossing. Despite this, 92 percent of pedestrians noted that the sign increased the likelihood that they would take additional precautions by stopping or looking both ways at the crossing, although whether these pedestrians actually continue to do so is not known.

3.1.1.4 Summary

Although drivers recognized the advance warning and crossbuck signs, many did not know where they were located in relation to the crossing, when the signs were used (e.g., many think that the crossbuck sign is used only at passive crossings), and the action that was required (Bridwell, et al., 1993; Dolan, 1996, Fambro, et al., 1994; Picha, et al., 1997). Several alternative sign systems that convey the action required have been proposed. The MUTCD allows the use of the stop or yield sign at grade crossings where two or more trains operate daily, and the NTSB has recommended the use of the stop sign at all passive grade crossings because it presents a consistent message that is well-understood by drivers (FHWA, 2003; NTSB, 1998). The use of the stop sign is controversial, and observations of its use at grade crossings showed a high rate of noncompliance (Burnham, 1994; Lerner, et al., 2002). The results of an accident analysis provide additional evidence that stop signs may not increase grade crossing safety; the crash rate over 10 years in seven Midwestern states was higher at crossings protected by stop signs than at crossings protected by crossbucks, flashing lights, or gates (Raub, 2006). More interest exists in the use of the yield sign at grade crossings or incorporating the yield message into sign systems at grade crossings. The results of studies examining the use of the yield sign have found that presenting a yield message in conjunction with the crossbuck improved driver understanding of the action required more than the crossbuck alone and was preferred by drivers over the presentation of the crossbuck alone (Bridwell, et al., 1993; Fambro, et al, 1994). However, field results addressing the presentation of the yield message on looking behavior were mixed (Fambro, et al, 1994, 1998; Russell and Kent, 1993).

Other studies have addressed methods to enhance the saliency of signs at grade crossings, and in particular, the conspicuity of the crossbuck. The current height of the crossbuck does not allow it to be illuminated effectively by vehicle headlights (Russell, 2002; Russell and Rys, 1997; Zwahlen and Schnell, 1999), so reflectorization of the crossbuck and crossbuck posts provides a high visual impact. Studies showed benefits for reflectorizing the signs at the crossing, which increased driver looking behavior (Russell and Kent, 1993), increased deceleration rates to the crossing (Russell and Kent, 1993), and increased the time between vehicles crossing the tracks and the train's arrival at the crossing (Zwahlen and Schnell, 2000).

Research on the design of signs for grade crossings has also addressed the need to provide additional information at the crossing. Lerner, et al. (2002) reported that a combination of the standard advance warning sign and crossbuck with supplementary signs that discriminated between active and passive crossings or provided warnings regarding specific site characteristics was more instructive than current sign systems. Additionally, several studies have examined the use of signs notifying drivers and pedestrians to the possibility of a second train's approach at a crossing (PB Farradyne, Inc., 2002; Sabra, et al., 2002). Demonstrations of these signs showed a positive impact on driver and pedestrian behavior in the short-term.

3.1.2 Pavement markings

Very few studies have evaluated the comprehension and design of current pavement markings since the publication of Lerner, et al. (1990). Only one study was identified addressing the issue of pavement markings, but its focus was on the use of supplemental markings that provided drivers with cues about whether there was sufficient space for their vehicle beyond the grade crossing. At crossings located near signalized highway intersections, drivers approaching the crossing must decide whether there is enough space to clear the tracks. In Europe, an "X" drawn in a box is painted on the roadway past the track. If the entire X is not visible before the driver begins to cross the track, then there is not enough space for the vehicle to safely clear the track.

The Florida Department of Transportation sponsored a study to evaluate the effectiveness of the Eurpoean X-marking by installing 25-ft (7.62 m) X-box pavement markings at one rural and one urban test site (Stephens and Long, 2003). Note that the length of the marking was large enough to accommodate most passenger vehicles but not larger road vehicles. It was expected that these larger vehicles would be primarily commercial, and thus operated by professional drivers who would be more sensitive and skilled at determining whether there was enough space for their vehicles beyond the tracks. Observations consisted of video data, collected before and after the installation of the pavement markings to determine how often drivers stopped in a hazard zone, an area approximately 15 ft (or 5 m) from either side of the closest and farthest rail.

The results of the study were inconclusive; the effectiveness of the X-box marking varied depending on the site. At rural intersections with few grade crossing signs and markings, the X-box marking improved safety, reducing the number of stops in the hazard zone by 60 percent. At busier intersections, where there were more crossing-related signs, markings, and signals, the X-box marking resulted in little, if any, changes to driver behavior. The authors attributed the benefits of the X-box markings at rural crossings to its high salience at those locations and considered the lack of an effect at busy intersections due to the effectiveness of the many grade crossing signs, markings, and signals at those urban intersections.

3.1.3 Active Warning Devices

Upgrading a passive crossing with active warning devices improves safety at the crossing, but the use of active warning devices is not foolproof. Upgrading a passive crossing with flashing lights *or* gates reduced the accident rate by only 44 percent, and upgrading a passive crossing by adding both flashing lights *and* gates reduced accident rates by 64 percent (Mortimer, 1988). In fact, in the 10 years from 1994 through 2003, approximately half of all grade crossing accidents occurred at crossings protected with active devices (Office of Inspector General, 2004). This is partially due to exposure; crossings protected by active warning devices generally have more vehicle and train volume, and thus a greater potential for conflicts.

The results of studies that have observed driver behavior at active crossings to determine the violations that occur are discussed below. Two general approaches to improve compliance at active crossings are considered. One approach is to explicitly improve compliance by providing barriers that prevent drivers from circumventing lowered gates. The second approach is to implicitly encourage compliance by improving the credibility of active warning systems (e.g., by reducing the waiting time at the crossing or by improving the perceived credibility of the warning system). Each of these approaches is discussed in more detail.

3.1.3.1 Violations at Active Grade Crossings

The most salient active protection system is the presence of flashing lights and gates. Upgrading a flashing light crossing with flashing lights and gates reduced the accident rate by approximately 44 percent (Mortimer, 1988). However, exposure at gated crossings is greater than that at non-gated crossings, so the accident rate at gated crossings is still high; in fact, in 2004, almost 33 percent of highway-rail incidents occurred at crossings protected by gates (FRA, 2004). To understand drivers' approach behavior to active crossings, Meeker, Fox, and Weber (1997) observed drivers at a crossing protected by flashing lights and half-barrier gates (approximately 13 ft (4 m) long) and compared it to observations collected 5 years earlier at that same crossing when it was protected with only flashing lights. The data collected consisted of whether the driver slowed upon approaching the crossing or stopped, the time between the onset of the warning signal and the arrival of the vehicle at the crossing, the time it took for the vehicle to clear the crossing, and the time of train arrival at the crossing. As expected, the number of crossing violations in front of oncoming trains decreased with the presence of gates. When the crossing was protected with flashing lights and bells, 67 percent of drivers crossed the tracks in front of an approaching train, but once the gates were added, only 38 percent of drivers violated the crossing. However, drivers who violated the gated crossing stopped or slowed significantly less than those who violated the flashing lights. Of the drivers who violated the gated crossing, 52 percent did not stop or slow down, 30 percent slowed down on their approach, and 17 percent stopped at the tracks before proceeding. Of the drivers who violated the flashing light crossing, 13 percent did not stop or slow down, 51 percent slowed on their approach and 36 percent stopped before proceeding. The authors hypothesized that the presence of gates forced drivers inclined to violate gated crossings into a hurried and risky crossing decision as they determine that the only way they can violate the crossing "safely" is without slowing or stopping. Such behavior would account for the substantial number of accidents at crossings protected by flashing lights and gates.

Abraham, Datta, and Datta (1998) conducted a similar observational study of driver behavior, classifying the types of violations that occur at grade crossings and identifying factors contributing to these violations. Drivers were observed at 37 Michigan grade crossings. All the crossings had active protection with either flashing lights only or flashing lights and gates. Observers recorded violations and noted the license plate of the violating vehicle and characteristics of the vehicle (make, model, and color) and driver (age and gender). The observed violations were classified according to risk level. *Routine* violations, the least risky, accounted for 27 percent of the violations. At gated crossings, routine violations occurred after the train cleared the crossing but before the gates were completely raised and the flashing red signal had stopped; at flashing light crossings, routine violations occurred when the driver violated the flashing red signal 4 seconds or longer after the train had passed. In committing these violations, the authors hypothesized that the driver perceived a low risk in not complying with the traffic control device because the train had already passed. *Risky* violations, those occurring immediately after the train crossed the intersection, accounted for 33 percent of the violations. At gated crossings, the driver crossed when the gates were still down and the lights were still flashing, and at flashing light crossings, the driver crossed within 4 seconds of the train's passage. Similar to routine violations, drivers perceived a low risk because the train had passed, but they did not consider the possibility of a second train approaching, a concern especially at multi-track crossings. *More risky* violations accounted for 19 percent of the observations. These violations occurred before the train's arrival at the crossing with active flashing lights. At gated crossings, these violations were those in which the driver crossed while the gates were lowering, and at flashing light crossings, these violations were those occurring 8 to 10 seconds before the arrival of the train. Not surprisingly, drivers committing *more risky* violations generally sped up to clear the crossing. *Severe* violations accounted for 19 percent of the violations. Drivers committed these violations before the train arrived, by maneuvering around lowered gates at gated crossings or crossing the tracks with a clearance time between 4 to 8 seconds at flashing light crossings. Drivers committing *severe* violations generally made a risk assessment of the situation before speeding up to cross the tracks. However, observations showed that once one driver violated the crossings, drivers behind the lead vehicle tended to follow without assessing the risk. Finally, 2 percent of the violations were considered "near-miss" situations, or *critical* violations, in which drivers crossed the tracks when the gates were down with a clearance time less than 5 seconds or at flashing light crossing, when the driver crossed the track with less than 4 seconds before the train's arrival. These violations tended to occur when the train was moving slowly.

Abraham, et al. examined the data on observed violations with respect to the crossings' crash history over the past 7 years to evaluate the effect of various site characteristics. They classified the 37 grade crossings into four groups based on the type of protection at the crossing (flashing lights only or flashing lights and gates), the number of tracks at the crossing (single or multiple), and the number of lanes on the approach (single or multiple). It is important to note that the classification of sites into these categories was not balanced. Of the 37 crossings, 24 were gated crossings with multiple tracks and multiple lanes on the approach, 6 were gated crossings with multiple tracks and single lanes on the approach, 8 were flashing-light crossings with single tracks and multiple lanes on the approach, and 5 were flashing-light crossings with single tracks and single lanes on the approach.

A comparison of the data across the four groups showed significantly more crashes at gated crossings with multiple tracks and multiple lanes on the approach than at flashing light crossings with single tracks and single lanes on the approach. The rate of violations at these gated crossings and flashing light crossings was not significantly different. Collectively, the results highlight the higher risk at gated crossings due to a higher exposure level and suggest that drivers may simply have had a better chance of clearing the intersection before the train's arrival in the absence of gates. Although the finding that more crashes occurred at gated crossings than flashing light crossings seems contrary to expectations, the result may be attributable to the nature of the roadways on the approach to the crossing rather than the protection system. The multi-lane approaches provided drivers the space to maneuver around the gates, and in fact the data also showed a significantly higher rate of crashes and violations at gated crossings with multiple lanes on the approach than gated crossings with single lanes on the approach. Flashing light crossings with single tracks and two-lane roads on the approach tended to have low-risk violations, and these violations were attributable to long warning times or driver misunderstanding of the flashing red light signal.

The results of Abraham, et al. (1998) highlight two approaches for improving compliance at active crossings. The first is to improve the traffic control device at gated crossings to provide a physical barrier to separate the traffic from the tracks to reduce violations at gated crossings. The second is to improve the credibility of the warning signal. Each of these issues will be considered in turn.

3.1.3.2 Improvements to Gated Crossings

Crossings with a large number of gate arm violations typically have one or more of the following features: they are located on a four-lane undivided roadway; they have two or more tracks separated by a distance greater than or equal to the storage requirement for one or more vehicles; there are large variations in train speed and warning time at the crossing; they are crossings at which a vehicle-train collision would pose a large safety problem (e.g., crossings traversed by a large number of school buses); and they have high accident rates (Heathington, et al., 1990). To reduce gate violations, improvements in gate technology have focused on systems that prevent drivers from going around the lowered gate arms. These systems include four-quadrant gates that have two extra gate arms to block both approach and departure lanes to the crossing, extended gate arms that cover more of the roadway to discourage drivers from maneuvering around lowered gates, median barriers installed along the roadway centerline to prevent drivers from crossing lanes, and vehicle arresting barriers in which a net barrier is lowered to block entrance to the crossing.

Several field studies have evaluated the effectiveness of these systems in reducing gate violations. Heathington, Fambro, and Richards (1989) reported that four-quadrant gates increased the safety margin at a grade crossing relative to two-quadrant gates. They collected observational data at one grade crossing for two months with a two-quadrant gate system and again for one to two months after the installation of a four-quadrant gate system. The results showed that the number of gate violations decreased from 84 out of every 100 train arrivals with the two-quadrant gate system to zero after the installation of the four-quadrant gate system, the number of vehicles crossing the tracks less than 20 seconds before the arrival of a train decreased from 60 per 100 train arrivals to zero, and the number of vehicles crossing less than 10 seconds before the arrival of a train decreased from 5 per 100 arrivals to zero.

Hellman, et al. (2001) reported similar decreases in crossing violations when they observed driver behavior at a grade crossing in Connecticut before and after a four-quadrant gate was installed to replace a two-quadrant gate. Data, collected for 13 months before the installation of four-quadrant gates and for 22 months after the installation, recorded the number of violations occurring after the warning lights had started flashing but before the gate arms had completely descended (described as Type 1 violations) and the number of violations occurring after the gate arms had fully descended (described as Type 2 violations). The violation rates were calculated per 100 train movements. The results showed that the installation of the four-quadrant gate system reduced both types of violations. The number of Type 1 violations decreased by four times from a rate of 85.2 per 100 train movements with the two-quadrant gate system to a rate of 21.4 per 100 train movements with the four-quadrant gates. The number of Type 2 violations decreased from three per 100 train movements with the two-quadrant gates to zero with the four-quadrant gates. As part of the study, Hellman, et al. also surveyed locomotive engineers to obtain their opinion on the use of the four-quadrant gate system. In responding to the survey, the engineers reported that the new gates reduced their anxiety level at the crossing without impacting their ability to control the train.

One concern in the implementation of four-quadrant gates is the timing with which the gates are lowered to ensure that vehicles do not become trapped between the gate arms. The operation of the four gate arms varies. The system may lower all four arms simultaneously, or it may delay lowering the gate arms on the exit side of the crossing to allow vehicles in the track zone to clear the area. The calculations to determine the gate delay and descent time for four-quadrant gates generally assumes that drivers are approaching the grade crossing at a constant speed. This, however, is not always the case. Moon and Coleman (1999) measured driving speed for passenger vehicles, trucks, and school buses at grade crossings and noted that vehicles tend to reduce their speed on the approach. Single vehicles approaching the crossing reduced their speed by approximately 5 mph. Groups of vehicles approaching the crossing reduced their speed even further, with the lead vehicle approaching at a higher speed than following vehicles. Thus, the timing of four-quadrant gates must be able to accommodate for this slowing behavior.

In contrast to four-quadrant gates that prevent vehicles from entering the track zone, median barriers prevent drivers from crossing into the opposite lane of traffic to maneuver around lowered gate arms. The Washington State Utilities and Transportation Commission and the BNSF (Burlington Northern Santa Fe) Railroad evaluated the effectiveness of median barriers in reducing gate violations at a grade crossing in Spokane, Washington. Video cameras installed at the crossing recorded the number of gate activations and incidents four months before and after the installation of median barriers. The incident rate was calculated as a function of the number of gate activations with a train present.

The median barriers reduced the number of incidents at the crossing from approximately 9 per 100 gate activations to 0.65 per 100 gate activations, a difference of approximately 14 to 1. The data was further analyzed to take into account the severity of the incident. For example, violations in which a vehicle crossed the occupied track were considered more dangerous than violations in which a vehicle crossed the unoccupied track but then stopped or reversed direction to avoid crossing the occupied track. When the analysis accounted for incident severity, the results showed the median barriers reduced the number of violations by a ratio of approximately 17 to 1, from 5 per 100 gate activations to 0.3 per 100 gate activations. Additionally, the number of "risky" crossings, that is the number of vehicles crossing the occupied track within seconds of a train's arrival, was reduced; the number of vehicles crossing the occupied track within 10 seconds of an approaching train decreased from 41 to zero, and the number of vehicles crossing the occupied track within 5 seconds of an approaching train decreased from five to zero. In fact, the minimum time with which a vehicle crossed in front of an approaching train when the median barriers were present was 15 seconds (Applied System Technologies, 2000).

The use of these improved barrier systems has received a lot of attention for deployment at grade crossings along high-speed rail corridors, where trains may travel at top speeds of 90 mph or greater. Median barriers and vehicle arresting barriers may offer a level of protection similar to that achieved with grade separation, and while four-quadrant gates do not offer this same level of protection, they have reduced violations at two-quadrant gate crossings with a history of driver noncompliance (Coleman, Eck, and Russell, 2000). Several of these barrier systems have been evaluated for use at different crossings along North Carolina's Southeast High Speed Rail Corridor. In 1992, the Washington, DC–Raleigh–Charlotte rail corridor was designated as one of five future high-speed rail corridors, and the state of North Carolina received special funding to improve grade crossing safety as part of this Sealed Corridor project. The State took a systems approach to evaluate new technologies to enhance current warning devices at grade crossings. The first improvements occurred at the Sugar Creek Road grade crossing in Charlotte. This grade crossing had the highest average annual daily traffic rate along the corridor with over 21,000 vehicles per day. The State installed median barriers and four-quadrant gates at this crossing. The median barriers consisted of prefabricated, mountable islands with flexible panel delineators or tubes that were highly reflectorized for visibility at night and were anchored so that they would return to their original position if hit by a vehicle. A four-phase observational study was conducted, in which video cameras recorded driver behavior at the crossing before and after improvements to the crossing had been made. In the first phase, only flashing lights, bells, and single arm gates protected the crossing. Median barriers were installed at the crossing in the second phase, and in the third phase, four-quadrant gates were installed without median barriers. The fourth phase included both four-quadrant gates and median barriers at the crossing.

Observations showed that there were approximately 43 close calls (i.e., near misses) per week when the crossing was protected with two-quadrant gates. The addition of median barriers reduced the number of close calls to approximately 10 per week, a 77 percent reduction in violations. Four-quadrant gates reduced the violation rate by 86 percent to six per week, and when the median barriers were used in conjunction with four-quadrant gates, the number of violations decreased by 98 percent to a rate of only one violation per week (Carroll and Haines, 2002; FRA, 2002; Hughes, Stewart, and Rogman, 1999; Vantuono, 1997).

The State installed longer gate arms that covered three-fourths of the roadway at a second crossing along North Carolina’s Southeast High Speed Rail Corridor, on Orr Road in Charlotte, with an average annual daily traffic of 11,000 vehicles per day. Observations of the number of crossing violations showed a 67 percent reduction in violations immediately after its installation, and an overall 84 percent reduction in violations one year later (FRA, 2002; Worley, 1999).

The use of these gate technologies, in conjunction with other safety improvements along North Carolina’s Southeast High-Speed Rail Corridor, has reduced the accident risk at these crossings. The difference in annual fatality rates at the crossings before and after improvements to the crossing were implemented was compared by examining crash history for the crossings between 1987 and 2000. The results of the analysis showed that approximately five lives were saved with the improvements, and that this accident reduction rate could be sustained even as traffic volume and train speed along the corridor increased by implementing similar improvements at additional crossings along the corridor (Carroll and Haines, 2002; FRA, 2002).

Vehicle arresting barriers were evaluated at grade crossings along the Chicago–St. Louis high-speed corridor. These systems consisted of flashing light signals and gate arms and included a fence-style net, similar to those used to stop planes on aircraft carriers. The net was lowered across the approach to a grade crossing when the warning signal was activated. Vehicle arresting barriers were installed at three grade crossings in Chicago, and driver behavior was observed at one of the three grade crossings to determine its effect on stopping and crossing behavior. The majority of drivers (83 percent) complied with the vehicle arresting barrier warning lights and stopped. In interpreting this result, it is important to note that the vehicle arresting barrier warning lights were different from the flashing light signals at the crossing, and thus some drivers who failed to stop might not have understood the action required when the vehicle-arresting barrier lights were activated. Nevertheless, the fact that the majority of the vehicles stopped and remained stopped was promising. Of the drivers who violated the warning lights, most did so without stopping, similar to the behavior observed at gated crossings by Meeker, et al. (1997). Only 1.5 percent of drivers who violated the crossing stopped before proceeding across the tracks (Coleman and Venktaraman, 2001).

Although the vehicle arresting barriers improved compliance, the cost of maintenance was high. The vehicle arresting barriers operated successfully 90 percent of the time during its demonstration period, but maintenance was performed frequently. Some of the maintenance calls were for routine work; others were for repairs due to intrusions or entanglements at the crossing. Video data showed four incidents in which a vehicle attempted to cross under the lowered net, and two instances in which the net dropped on top of a vehicle. Each of these incidents cost between $6,000 and $8,000 for repair. A cost-benefit analysis of the use of vehicle arresting barriers at all three crossings indicated that while the barriers were predicted to reduce the number of grade crossing accidents, the systems were not cost effective due to the maintenance required (Sööt, Metaxatos, and Sen, 2004).

3.1.3.3 Improving Warning Device Credibility

Instead of installing barriers at the crossing to prevent violations, an alternative approach is to encourage drivers to comply by improving the perceived credibility of the warning device. The results of field studies discussed in Section 3.1.3.1 indicated that some drivers would violate an active signal regardless of the level of protection at the crossing (Abraham, et al., 1998; Meeker, et al., 1997), possibly due to the drivers' perceived lack of credibility for the warning signal. In a focus group examining attitudes towards warning devices, many drivers indicated that they did not rely on the information provided by active warning devices because they felt that warning devices operated improperly. The reasons cited for the perceived failure were that the warning devices were activated too early, remained active for too long past the crossing event, or malfunctioned frequently (Global Exchange, 1994). The effect of warning time and signal reliability on driver compliance will be discussed in more detail. Countermeasures to improve drivers' perceived credibility of warning devices are also addressed.

Reducing Warning Time

The MUTCD requires that active warning devices provide a minimum warning time of 20 seconds before the arrival of a train at grade crossings where trains operate at speeds of 20 mph or higher. As train speed varies, however, the warning time at crossings becomes unpredictable. Wilde, Hay, and Brites (1987) measured the warning time of signals and total signal duration at five grade crossings in Ontario, three protected by flashing lights and bells and two protected by gates. They found that the length of the warning time and signal duration varied considerably, both at a grade crossing and across all the grade crossings observed. Warning time ranged from 13 seconds to 73 seconds; at one crossing, the average mean warning time was 58 seconds. The signal duration varied from 28 seconds to over 9 minutes, with an average time loss to drivers between one to three minutes. This variability in warning time and signal duration had an observable effect on driver behavior. As part of the study, Wilde, et al. (1987) videorecorded vehicles at seven grade crossings when they were within 328 ft (100 m) of the approach to the crossing (note that two of the crossings were passive crossings and protected by crossbucks only). Incidents occurred in approximately half of the train approaches. Although some drivers violated the crossing unintentionally (i.e., the signals at the crossing started to flash at a point where the driver could not safely stop the vehicle), observations also showed drivers deliberately disregarded signals and violated the crossing. Although the observations only detail the violation and not the drivers' motivations for violating the grade crossing, the authors noted that the rate of violations was highest at the crossing with the highest warning time relative to the other crossings.

As the warning time increases, the number of violations also increases. A logistic regression model created by Carlson and Fitzpatrick (1999) indicated that waiting time was a significant variable in high violation rates at grade crossings. Similarly, in the study by Coleman and Venktaraman (2001), discussed in Section 3.1.3.2, the number of violations to the vehicle-arresting barrier lights increased as the warning time at the crossing increased. The mean warning time at the crossing was 55 seconds, with an overall range from 26 seconds to 93 seconds. No violations occurred when the waiting times were less than 20 seconds because the barrier nets and gates began to lower within this time interval. However, the number of violations increased by approximately 10–15 percent for every 10 second delay beyond 20 seconds.

Richards and Heathington (1990) found that most drivers expect a train to arrive within 20 seconds of the onset of the active control device, and that the number of drivers who stop and wait at a crossing declines when the waiting time extend.s beyond that. They conducted field observations and a laboratory study to determine driver tolerance to waiting times at grade crossings. In the field study, they observed drivers at two flashing light crossings and one gated crossing to determine their willingness to wait based on their arrival time to the crossing relative to the train's arrival time. Observational data indicated that at flashing light crossings, over 95 percent of drivers stopped and waited when arriving at the crossing within 10 seconds of the train, over 50 percent stopped when arriving within 10 to 20 seconds of the train, but only 30 percent stopped and waited when arriving with more than 20 seconds before the train. At the gated crossing, over 80 percent of drivers arriving at the crossing within 20 seconds of the train stopped and remained stopped, but the number of drivers who did so decreased sharply as the waiting time increased beyond 20 seconds. The data also showed that the majority of drivers arriving at an active crossing at the onset of the signals were unlikely to wait. At flashing light crossings, the majority of drivers who arrived at the crossing within 5 seconds of the onset of the signals ignored the warning device, even though they had sufficient time to stop. At the gated crossing, drivers approaching the crossing at the onset of the signal did not stop or react to the onset of the signal; in fact, 60 percent of drivers crossed without stopping in the first 9 seconds of the warning period suggesting that drivers' first response to the onset of the flashing light warning was to try to beat the gates.

To determine drivers' expectations and tolerance regarding warning times, Richards and Heathington conducted a laboratory study in which they showed drivers videotapes of traffic control device activation events and asked them to indicate two points in time: (1) the time they would expect the train to arrive at the crossing and (2) the point at which they considered the waiting time too long. Half of the drivers watched a video of a flashing light crossing; the other half watched a video of a crossing with flashing lights and gates. The results showed that at flashing light crossings, drivers expected a train to arrive within 14.5 seconds of the signal activation, with a mean waiting time of 39.7 seconds. At crossings with gates and flashing light signals, drivers expected a train to arrive within 30.6 seconds of the signal activation (13.2 seconds excluding the gate delay and descent time), with a mean waiting time of 66.2 seconds (48.8 seconds excluding the gate delay and descent time). At first glance, the data suggests that the mean acceptable waiting time at gated crossings was significantly higher than that for flashing light crossings, but there was actually little difference between the two once the gate delay and descent time was excluded. That is, drivers did not appear to consider the gate delay and descent time in calibrating their expected waiting time at a crossing. However, the mean waiting time for the two types of crossings did differ, even after the gate delay and descent time was subtracted, suggesting that drivers accepted a longer waiting time at gated crossings, possibly due to the more restrictive appearance of the gates.

Constant warning time systems that present a uniform waiting time are expected to improve compliance. Several studies have compared the use of constant warning time systems to fixed-distance systems, with mixed results. Halkias and Blanchard (1989) conducted an accident analysis in which they compared the accident rate at crossings protected by constant warning time systems to that at crossings protected by fixed-distance systems between 1975 through 1984. Although the analysis showed no overall benefit for constant-warning time systems, an examination of the warning times at fixed-distance crossings suggested that inconsistent warning times led drivers to distrust the warning signals, and extended warning times resulted in crossing violations. The authors hypothesized that because drivers were unaware of whether the crossing was equipped with a constant-warning time system or fixed-distance warning system, the inconsistency of warning times at crossings equipped with fixed-distance warning systems may have reduced credibility for warning signals in general. Consequently, benefits for constant warning time systems were not observed.

Bowman (1989) reported similar results for an accident analysis of vehicle-train incidents using data from 1980 through 1984 from crossings equipped with constant warning time systems and fixed-distance systems. While fewer accidents occurred at crossings with constant warning time systems than at crossings with fixed-distance systems, this difference was not significant. Bowman attributed the lack of a significant difference to one of two reasons. The first was the low credibility for warning signals in general resulting from long warning times at crossing equipped with fixed-distance systems, as noted by Halkias and Blanchard. The second was the small sample size of accidents at grade crossings with constant warning time systems. To obtain more data, Bowman conducted a field study in which he observed driver behavior at 12 grade crossings, half that were equipped with constant warning time systems and half with fixed-distance systems. Half of these sites were equipped with flashing lights only, and the other with flashing lights and gates. The field analysis showed significant reductions in violations at crossings protected with constant warning time systems. Most of the violations occurred when the warning time was greater than 50 seconds, even at gated crossings. At flashing light crossings, violations increased when the warning time exceeded 35 seconds.

More recently, Richards, Heathington, and Fambro (1990) conducted a before and after study comparing driver behavior at an active grade crossing equipped with a fixed-distance warning system to subsequent behavior with a constant warning time system. They collected data for a 2-month period before and after the installation of the constant warning time system. Data for the “after” phase was collected two months after the installation of predictors so that drivers could become familiar with the change in warning time at the crossing. An analysis of warning times showed that the constant warning time system reduced the mean warning time at the crossing (from 75.2 seconds to 41.7 seconds) and reduced the number of excessively long warning times. Driver compliance with the crossing improved, with a reduced number of cars crossing against activated flashing light signals, a reduced number of cars crossing within 10 seconds of the train’s arrival, and a decreased average speed for the first vehicle approaching the crossing.

Improving Warning Reliability

The perceived credibility of the warning system is determined not only by the waiting time but also by the number of false alarms or missed signals. False alarms occur when a warning signal is activated at a grade crossing when no train is approaching. On the other hand, missed signals occur when a warning signal is not activated when a train is approaching. Even though both false alarms and missed signals contribute to the drivers' perception of the warning signals' reliability, generally false alarms at grade crossings result in a lack of compliance whereas missed signals lead to more cautious behavior.

Wilde, et al. (1987) recorded the signal reliability of active warning devices as part of his observational study of incidents at grade crossings, as previously described. The data indicated that false alarms at the grade crossings observed were relatively infrequent. False alarms occurred at only one of the grade crossings, but at this crossing, false alarms accounted for 50 percent of the warning signal activations. Observations of driver behavior noted a high rate of violations at this crossing with respect to other crossings, although, as noted above, the drivers' specific motivations for violating the crossing were not known.

Gil and Multer (in preparation) conducted two studies to evaluate the effect of warning signal reliability on driver compliance at active grade crossings. In the first study, they applied signal detection theory to measure participants' sensitivity to the reliability of a warning signal and their response bias when confronted with an ambiguous grade crossing situation. Participants indicated whether they would stop or proceed when shown trials that contained an image of a gated crossing with the gate arm in the lowered position; in other words, when the warning device signaled an approaching train. The signal reliability was varied at eight levels from 23 percent to 97 percent, but participants were not informed of the reliability level beforehand. Instead, participants were primed to reliability of the warning signal by providing feedback after each trial that indicated the accuracy of their last response. Participants' responses were classified into four categories: a *valid stop*, in which drivers were compliant to a reliable and accurate signal; a *false stop*, in which drivers were compliant to an unreliable signal that provided an alert a train's arrival when in fact no train was approaching; a *high-risk violation* in which drivers disregarded a reliable and accurate signal; or a *no-risk violation*, in which drivers disregarded an unreliable and inaccurate signal. The results indicated that participants required a high degree of system reliability before they became sensitive to the differences between a reliable warning versus a false alarm. As reliability increased, participants' were more conservative in their responses and were more likely to comply with the warning signal. This bias resulted not only in more valid stops but also in more false stops. Although this more cautious behavior seems desirable, false stops could actually have a negative impact on driver behavior and contribute to under trust of activated warning signals. In fact, the results of the study also showed that when participants perceived the warning signal to be unreliable, they were more likely to proceed and commit a gate violation.

In the second study, Gil and Multer examined participants' response at grade crossings as a function of warning signal reliability in a more realistic driving situation. The reliability of the warning signal was varied at three levels: 40 percent, 60 percent, and 83 percent. Participants were first primed to the reliability of the warning signal using the procedure from the first study, described above, with three modifications. First, trials contained not only images of active gates (with lowered arms) but also images of inactive gates (with raised arms). Second, half the trials included a train horn that indicated an approaching train. Third, participants no longer received feedback regarding the accuracy of their response as the other two modifications reduced the difficulty of the task. After completing the priming task, participants drove a simulated vehicle on a course with active grade crossings.

The results of the priming task showed that similar to the previous study, as warning reliability increased, driver compliance also increased. However, unlike the previous results, drivers erred on the side of caution when presented with unreliable information. In the driving task, the likelihood that participants complied to the warning signal increased as signal reliability increased from 40 percent to 60 percent, with no additional improvement when reliability increased from 60 percent to 83 percent. Most of the vehicle-train collisions occurred when the signal reliability was 40 percent, the lowest level. An analysis of driving time showed that participants completed the course fastest in this low reliability condition, mostly attributable to the fact that two-thirds of the participants did not comply with any of the warning signals along the course. Additionally, the time to impact, defined as the time between the vehicle crossing the tracks and the train's arrival time, was lowest (4.18 seconds) when signal reliability was only 40 percent.

The results of Wilde, et al. and Gil and Multer highlight the impact of signal reliability on the perceived credibility of the warning system, and in particular, the negative effect of false alarms. Research in other domains has also found that systems with frequent false alarms are ignored or result in slower response times to the event (Getty, et al., 1995; Parasuraman, Hancock, and Olofinboba, 1997; Sorkin, 1988). Warnings that present operators with an alert when a predefined threshold is exceeded may be mistrusted or ignored if the thresholds are too sensitive (Billings, 1997). In the aviation domain, Parasuraman and Riley (1997) reported that alerting systems in aircraft, such as the ground proximity warning system, which indicate to the pilot when the aircraft is too close to the ground, were sometimes disabled because of their propensity for false alarms.

Thus, countermeasures to reduce the false alarm rate to improve the perceived credibility of active warning devices should be considered; for example, by identifying signal malfunctions and repairing them without delay. Alternatively, research has examined the effectiveness of warning devices that are considered to be more credible than the current active warning devices to encourage compliance. Section 3.1.1.1 discussed the use of stop signs and yield signs at passive crossings. For active crossings, there is interest in incorporating the standard highway traffic signal.

Use of Traffic Signals

Drivers believe highway traffic signals to be credible. As a result, the expectation is that drivers will be more likely to comply with a highway traffic signal at a grade crossing than with a flashing light signal, particularly at crossings near signalized intersections and crossings with complex geometries and driving maneuvers where drivers may have a difficult time determining whether it is safe to proceed across the tracks (Heathington, et al., 1990). Traffic signals were originally proposed as an alternative to flashing light signals to provide more information to drivers. In particular, drivers who are in close proximity to a grade crossing when the flashing lights are activated must decide whether to stop, knowing that they cannot do so safely, or to continue and violate the crossing. The yellow light would provide drivers with a pre-warning signal, indicating when there is an impending change in the right-of-way (Heathington, 1996; Van der Horst, 1988).

In observations of drivers at grade crossings in the Netherlands to determine behavioral factors contributing to grade crossing accidents, Tenkink and Van der Horst reported that some drivers, who approached the crossing at the onset of the red signal, stopped at the grade crossing by decelerating rapidly at a rate greater than 9 miles per hour second (4 m/s^2), and a few drivers stopped close to the first railway track. These stops could result in rear-end collisions by a following car or lead to drivers stopping on the tracks, and could be prevented by the presentation of a yellow light. Additionally, their observations noted that 15 percent of the drivers crossed the tracks as soon as the train cleared the intersection while the flashing red light signals were still activated. Presentation of the yellow light could reduce ambiguity at the end of the red phase, indicating to the driver when it is safe to proceed.

Fambro, Heathington, and Richards (1989) evaluated the effectiveness of an enhanced traffic signal to the standard flashing lights in reducing grade crossing violations. They observed driver behavior at a flashing-light crossing two months before and after the installation of a traffic signal with white bar strobe lights in each of the red signal lens. Observations showed that the traffic signal reduced the number of crossing violations by 80 percent from that with the standard flashing light signal; there were 3.35 violations per signal activation for the flashing light signal and 0.73 violations per signal activation for the traffic signal. Additionally, the number of drivers who violated the signal within 20 seconds of an approaching train decreased from 0.78 for the flashing light crossings to 0.24 with the traffic signals. While the number of "risky" crossings, characterized as crossing within 10 seconds of an approaching train, was also lower with the traffic signals (0.05) than with the standard flashing lights (0.13), there were not enough observations for a rigorous statistical analysis. There was no difference in driver's approach speed, braking behavior, or deceleration levels.

Because traffic signals are less expensive to install than traditional active warning devices, enhanced traffic signals may be applicable in the grade crossing domain and used at crossings where flashing light signals are needed. Drivers perceive highway traffic signals to have a high level of credibility because they are typically well-operated and maintained when used at highway intersections. These same standards of operation and maintenance will be needed if traffic signals are used at grade crossings so that driver credibility for the traffic signal is not compromised. In particular, traffic signals should not be used at crossings where false activation or malfunction of signals is frequent or at crossings where the warning or occupancy times are higher than 1 minute (Heathington, et al., 1990).

3.1.3.4 Summary

Active warning devices increase the level of safety at a grade crossing relative to passive crossings, but because exposure at active crossings is higher than at passive crossings, the accident rate is still high. Observations of driver behavior at active grade crossings indicated that some drivers were quite willing to violate active warning signals, and that the presence of lowered gates could be viewed by some drivers as an impediment to beating the train at the crossing resulting in rushed and unsafe crossing decisions (Abraham, et al., 1998; Meeker, et al., 1997). Compliance at active crossings may be improved explicitly by implementing barrier-type gate systems to prevent drivers from maneuvering around lowered gates or may be encouraged implicitly by improving the driver's perceived credibility of the active warning device. With respect to the former, the results of observations from field studies noted the effectiveness of four-quadrant gates (Heathington, et al., 1990; Hellman, et al., 2001), longer gate arms (FRA, 2002; Worley, 1999), and median barriers (Applied Systems Technologies, 2000; Carroll and

Haines, 2002; FRA, 2002, Vanutono, 1997) in improving compliance relative to two-quadrant gates. The use of these improved gate systems reduced the violation rate at the crossing and increased the “time to impact” (i.e., the time between a vehicle crossing the tracks and the arrival of the train). Although the use of vehicle arresting barriers was effective at reducing violations (Coleman and Venktaraman, 2001), the costs of maintaining the system was greater than its anticipated safety benefits (Sööt, et al., 2004).

With respect to the latter, the perceived credibility of warning signals is reduced by long warning times and frequent false alarms (Global Exchange, 1994). Examination of driver tolerance to warning times indicated that most drivers expected trains to arrive within 20 seconds of the activation of the warning signal (Richards and Heathington, 1990), and the likelihood that drivers would not comply increased as the warning time extended beyond that point (Bowman, 1989; Coleman and Venktaraman, 2001; Richards and Heathington, 1990). One countermeasure to reduce the length of the warning time is the use of constant warning time systems, as noted in Lerner, et al. (1990). Several studies have been conducted since the publication of their report evaluating its effect on driver behavior. The results of accident analyses comparing the accident rate at crossings equipped with constant warning time systems and fixed distance systems have generally shown no differences between the two (Bowman, 1989; Halkias and Blanchard, 1989). However, low sample sizes or low signal credibility due to long wait times at crossings without constant warning time systems may account for the lack of a difference. On the other hand, the results of field studies in which driver behavior was observed at crossings with constant warning time systems have generally reported significant reductions in crossing violations relative to crossings protected with fixed-distance systems (Bowman, 1989; Richards, et al., 1990). False alarms due to malfunctioning signals also account for unnecessary wait times. Signal reliability is a function of the rate of false alarms and missed signals, with frequent false alarms leading to noncompliance (Gil and Multer, in preparation; Wilde, et al., 1987) and missed signals in more cautious behavior and potentially unnecessary compliance.

Countermeasures to improve the perceived credibility of active warning signals have also included the use of highway traffic signals. Because drivers believe traffic signals are credible, they may be more willing to comply (Heathington, et al., 1990). One field study showed that the use of an enhanced traffic signal, with white bar strobe lights in the red signal lens, reduced crossing violations relative to the standard flashing light signals (Fambro, et al., 1989), but no significant research has been conducted regarding its use. One note of caution should be mentioned. The use of traffic signals at grade crossings could impact drivers’ perceptions of credibility for traffic signals in general and thus, traffic signals should not be used at crossings where signals malfunction frequently or at crossings with high waiting times (Heathington, et al., 1990).

3.2 Crossing Characteristics

Some drivers do not realize they are approaching a grade crossing. Driver detection of the grade crossing is difficult at night if it is not illuminated, and physical characteristics of the crossing may limit its visibility. Both these factors delay detection and recognition of trains at or approaching the crossing and may contribute to approximately 10 percent of all crossing accidents (Lerner, et al., 1990). Methods to increase the conspicuity of the crossing at night and to mitigate the effect of sight restrictions are addressed in this section.

3.2.1 Illumination

Visual search at night is more constrained than it is during the day. Examination of drivers' eye movements show that at night, drivers were most focused on the road directly ahead in the areas illuminated by headlights, but during the day, drivers focused not only on the scene directly in front of them but also to areas to the right and left (Rackoff and Rockwell, 1975). To compensate for these limitations in visual search at night, drivers generally adopt a more conservative approach behavior. Studies have found that drivers approached crossings at slower speeds and were less willing to commit crossing violations at night than during the day.

In one such study, Ward and Wilde (1995) compared approach speed and brake light activations to grade crossings in daytime and nighttime conditions. Vehicle approach speed was tracked at eight incremental distances from the crossing, and two observers recorded whether drivers applied their brakes as they approached the crossing. Although flashing lights and bells protected the crossing, all observations occurred when the signals were inactive. The results showed that both approach speed and brake-light activation was lower at night than during the day, suggesting that drivers were reducing their speeds prior to the approach at night (and hence, less braking) rather than modifying their speed on the approach as they did during the day.

Richards and Heathington (1990) observed similarly cautious behavior, in their study measuring acceptable warning times at active grade crossings (discussed in Section 3.1.3.3). Their observations showed that 20 percent more drivers stopped and waited at the gated crossing at night than during the day. Thus, drivers appeared less willing to try to beat the train due to the reduced visibility.

At night, simply illuminating the grade crossing can increase its conspicuity. Mather (1991) conducted a small study in which he compared the number of train-vehicle accidents at grade crossings in Oregon from 1984 through 1989, the time period when the Oregon Public Utility Commission began illuminating crossings as a low-cost alternative to improving safety. Crossings that had regular nighttime movement but had too low train or vehicle volume to qualify for automatic warning device were equipped with illumination devices. In his study of 34 crossings, he noted that illumination reduced the number of nighttime grade crossing accidents from 18 accidents at 13 of those crossings to three at two crossings.

3.2.2 Sight Restrictions

Drivers should be able to determine whether or not a train is approaching a crossing with enough time to stop safely at a distance of 15 ft (4.5 m) from the track (FHWA, 2002). However, sight restrictions often exist due to terrain, vegetation, or other structures, which cannot be easily removed or it would be economically infeasible to do so. An NTSB (1998) safety analysis of 60 passive grade crossing accidents noted that one-third of the accidents in the study were attributable to physical characteristics of the crossing, such as inadequate sight distance, oblique angles to the crossing, curvature of the roadway or railroad track, or vertical alignment to the crossing. In particular, limited sight distance has often been cited as a contributing factor to accidents at passive crossings (Mortimer, 1988; Russell, 2002), although no data exists to support this claim (Messick, 1994; Ward and Wilde, 1996; Wigglesworth, 2001).

Observations of driver looking behavior at grade crossings suggest that drivers do not usually consider sight limitations a problem. Wigglesworth (2001) observed driver behavior at one passive grade crossing with limited sight distance at three of the four quadrants. Surprisingly, he found no difference in looking behavior between drivers traveling in either direction.

Approximately 33 percent of the drivers looked in both directions, 33 percent looked in only one direction, and 33 percent looked in neither direction.

Ward and Wilde (1996) hypothesized that drivers know that their view of the tracks is restricted and modify their approach speeds to compensate. They observed driver behavior at a passive grade crossing before and after the lateral sight distance was enhanced by clearing vegetation that obscured drivers' view. The observations showed that as the sight distance increased, drivers increased their speeds to the approach, thus resulting in no net safety benefit. A survey of local residents, conducted to determine their perceptions on whether or not safety of the approach was improved, indicated that most drivers noticed the improvements and felt that their level of risk was lowered.

3.2.3 Increasing Crossing Conspicuity

Several methods have been proposed to improve detection of grade crossings; examples include "illuminated" signs, flashing lights, and strobe lights. Russell and Rys (1996) evaluated the use of a sign they called the Passive Warning Sign, which is made from a material that redirects the train's headlights so the sign is illuminated when a train approaches the crossing. The Passive Warning Sign is intended for use in conjunction with the standard crossbuck and can be used to display messages to the driver. Russell and Rys conducted field studies in which participants were driven across grade crossings equipped with the Passive Warning Sign system and asked to indicate the distance at which the sign was recognized and the distance at which the text could be read. In the field evaluation, the Passive Warning Sign contained the text "yield" written vertically in white capital letters on a red background. Participants viewed the sign in daylight and nighttime conditions. The results showed that the Passive Warning Sign did not detract attention from the crossbuck and was detectable at a far enough distance when approaching the crossing at 55 mph that the driver could take safe action at the grade crossing, if needed. However, discussions with participants afterwards indicated public education regarding the location of the sign would be needed before implementation.

Studies have also evaluated the use of flashing lights or strobe lights, presented in conjunction with current warning signs at the crossing. Fambro, et al. (1998) compared the presentation of the advance warning sign to an advance warning sign with a flashing beacon and an advance warning sign with a strobe light. In their study, participants drove through a test course containing the three advance warning systems with an in-vehicle observer who recorded driver actions. After driving the test course, participants ranked each of the advance warning systems based on their ability to attract attention and redirect attention to the driving task. Observations of driver behavior showed that drivers exhibited more caution, as shown by increased braking, as they approached the crossings with the two experimental light systems. More importantly, neither of the light systems resulted in any adverse driving behavior (e.g., slamming on the brakes or erratic driving maneuvers). Participants' preference ratings indicated that the two advance warning systems with lights were preferred to the standard advance warning sign in attracting attention. However, the presentation of the supplemental lights was somewhat confusing to drivers, who were uncertain of its meaning. Some thought that the flashing light implied that a train was approaching, and this impression was greater with the use of the flashing beacon than with the strobe light.

These two advance warning systems evolved into a third prototype system that consisted of the advance warning sign, a vehicle-activated strobe light located above the advance warning sign, and a supplemental sign below the advance warning sign stating "Look for Train at Crossing" (Fambro, Noyce, Frieslaar, and Copeland, 1997; Noyce and Fambro, 1998). This new sign system was installed at a passive grade crossing and evaluated with a before and after field study comparing vehicle speeds. To obtain driver feedback on the system, drivers, who had passed the crossing, were stopped and asked to recall the approach to the crossing and whether they had noticed anything different about the crossing relative to other crossings. The results showed that the strobe light plus sign system increased drivers' awareness of the crossing, as measured by reduced approach speeds to the crossing. Fifty-two percent of drivers who participated in the driver survey reported that they noticed something unique about the crossing. Of these drivers, 88 percent were able to attribute it to the strobe light, and 71 percent identified the supplemental sign. Not surprisingly, drivers were more likely to notice the strobe light as illumination decreased. More interestingly, drivers who were familiar with the crossing were *less* likely to notice the experimental system. When drivers were asked what message they thought the strobe light conveyed, many drivers responded that they associated the strobe light as an indication that they should exercise more caution when approaching the crossing. None of the participants confused the activation of the strobe light with the presence of a train at the crossing.

3.2.4 Summary

Detection of grade crossings is more difficult at night, when drivers rely on a different set of cues than during the day (Rackoff and Rockwell, 1975). Additionally, inadequate sight distance along the track hinders the detection of trains at the crossing or approaching the crossing (NTSB, 1998). To compensate for these reductions in visibility, drivers have generally adopted a more conservative approach behavior (Richards and Heathington, 1990; Ward and Wilde, 1995; Ward and Wilde, 1996). Countermeasures to improve the conspicuity of the grade crossing have included illumination (Mather, 1991), the "illumination" of signs when a train is at the crossing (Russell and Rys, 1996), or the use of strobe lights in conjunction with the advance warning signs and a supplementary sign reminding drivers to look for trains (Fambro, et al., 1997; Fambro, et al., 1998; Noyce and Fambro, 1998).

3.3 Train

The large size of trains and their dark colors combined with low illuminations or limited visibility hinder their detectability (Lerner, et al., 1990). Approximately 26 percent of all grade crossing accidents from 1975 to 1996 involved a vehicle striking a train, with 53 percent of these accidents occurring at night (Carroll, et al., 1999). Thus, additional warnings regarding the presence of a train are needed to improve safety at grade crossings.

Several warning devices on trains can improve their conspicuity. The train may be equipped with active and passive lighting systems to improve its detectability in low illuminations. Active systems, such as oscillating lights, rotating beacons, strobe lights, crossing lights, ditch lights, or ground lights, emit light to the driver, whereas passive systems, such as reflectorization, reflect light from vehicles. In addition to visual indications of a train's approach to or presence at a crossing, the train horn provides auditory alerts. The use of these three on-train devices (i.e., active alerting lights, reflectorization, and the train horn) and technological advances that have improved their effectiveness in enhancing train conspicuity is addressed.

3.3.1 Active alerting lights

Although a train's headlights provide a signal to the driver that it is approaching a grade crossing, its headlights were not originally intended to be used as an alerting system and may not be as effective as other systems. As Lerner, et al. (1990) noted, the standard headlight is not very conspicuous due to its narrow beam width, particularly during the day, when the angle illuminated by the train's headlight will most likely be smaller than the angle between a vehicle and an approaching train.

The FRA initiated a program to examine the conspicuity of various external alerting lighting systems in 1991. As part of this program, Carroll, Multer, and Markos (1995) conducted a comprehensive evaluation of visual alerting devices in several field studies to provide input to the FRA's effort to develop regulations for locomotive conspicuity. Rail operations have used various alerting lights, and the FRA provided specifications for the color, operational aspect, and horizontal and vertical spacing for the use of oscillating lights, strobe lights, ditch lights, and crossing lights. In particular, specifications regarding the spacing of the lights allowed the FRA to define a distinctive triangular pattern that could facilitate driver detection and recognition of a train and estimations of its location with respect to the crossing.

Carroll, et al. conducted a controlled field test to evaluate the effectiveness of some of these lighting systems relative to the standard headlight. Two trains were equipped with strobe lights, ditch lights, and crossing lights and operated at a simulated grade crossing site at a railway yard facility. The crossing lights operated in a flashing mode and the ditch lights in a steady burn mode. The alerting lighting systems were presented one at a time in conjunction with the standard headlight. The strobe lights were mounted on the roof of the train, the ditch lights were mounted on the outside corners of the train and angled 15º outward from the train, and the crossing lights were mounted on the centerline of the train. Participants, seated 205 ft (62.5 m) from the simulated grade crossing, were asked to indicate when they first noticed a train approaching in their periphery while performing a visual monitoring task on a laptop computer that simulated the attentional demands of driving. Participants wore headphones so they could not hear the train approaching. Once participants detected the train, they performed a distance estimation task by indicating when the train was a specified time interval away from the crossing (e.g., 22, 17, 12, or 7 seconds). Half of the participants performed the tasks during the day, and the other half performed the tasks at night.

The results showed that the train was detected at greater distances when it was equipped with any of the auxiliary alerting lights relative to the use of the standard headlight alone. Participants detected the train at the greatest distance when it was equipped with the crossing lights, followed by the ditch and strobe light systems. Not surprisingly, detection distance for all three systems was greater at night than during the day. This difference in ambient light level did not affect drivers' judgments of train arrival time. In general, participants tended to judge the train as being farther away from the crossing than it actually was, therefore leading to overestimates in the train's arrival time. The degree of this overestimation increased as the estimated arrival time increased beyond 12 seconds. Arrival time judgments were most accurate for crossing lights, followed by the strobe and ditch light systems. Use of the standard headlight, alone, resulted in the highest number of overestimations.

Carroll, et al. then conducted an in-service operational test of the alerting light systems to determine the capital costs, maintenance requirements, operational concerns, and potential safety benefits of their use. The effect on safety is of specific interest here. In the field test, two crossing lights, used in conjunction with the standard headlight, were installed on the locomotives of three participating railroad companies for a 2-year period. To measure the safety impact, accident data prior to, during, and after the installation of the crossing lights were collected and compared. The accident rates were normalized by the level of train operations with and without the use of alerting light system to control for exposure level. The results showed decreases in accident rates of 76.4 percent, 74.3 percent, and 54.6 percent for the three railroads with trains equipped with the crossing lights versus those equipped with the standard headlight alone. While the results were promising, the data collected was limited. The authors also acknowledged the possibility that the novelty of the crossing light system or other factors, such as public education or enforcement programs, that were not accounted for in the study, influenced driver behavior.

A larger accident analysis to determine factors contributing to improvements in grade crossing safety noted the benefits of alerting lights. Mok and Savage (2005) analyzed nationwide data on grade crossing accidents and incidents from 1975 through 2001 using a negative binomial regression analysis. The use of ditch lights was only one of several explanatory variables included in the analysis; other variables included the amount of vehicle and rail traffic, the protection at the crossing, highway safety measures, and Operation Lifesaver (to be discussed in more detail in Section 6.2). The results of the regression analysis indicated that the use of alerting lights had a large safety impact. Estimates suggested that equipping trains with ditch lights reduced the number of grade crossing incidents by 29 percent and the number of fatalities by 44 percent. Additionally, whereas the data showed that safety at grade crossings improved steadily since 1979, further examination showed a period of swift decline of 30 percent from 1994 to 1998, which coincided with the FRA's requirement to install crossing or ditch lights on locomotives. Although the results of the regression analysis by Mok and Savage show the benefits to the use of ditch lights, it is important to note that the analysis conducted did not include a comprehensive list of factors due to limitations in the databases used. As a result, the relative contribution of the factors that were included may be overestimated, and the impact of ditch lights, while still positive, may not be as high as predicted by their analysis.

Regardless, the use of alerting lights has been successful in increasing the conspicuity of the train and the triangular pattern in which the lights are placed has been effective in allowing drivers to judge the train's distance from the crossing and its speed. The FRA Final Rule regarding the use of alerting lights is discussed in *Railroad Locomotive Safety Standards: Clarifying Amendments; Headlights and Auxiliary Lights; Final Rule* and codified in 49 CFR § 229.

3.3.2 Reflectorization

Trains may also be equipped with passive alerting devices, such as reflective markers, to increase their conspicuity. Reflectorization is already used by several railroads in the U.S., Australia, and Canada and is expected to reduce the number of grade crossing accidents in which a vehicle runs into a train. By increasing the conspicuity of all rail cars, it is anticipated that reflectorization will prevent accidents in which the vehicle collides with a train after the lead locomotive car has entered the crossing.

The benefits of reflectorization were initially limited by the degradation of its intensity over time due to railroad environmental conditions. As a result, the reflective markers required frequent maintenance or replacement (Lerner, et al., 1990). However, improvements in reflective materials resulted in enhancements to their brightness and durability and thus the use of reflectorization warranted further evaluation. This was the goal of a series of studies conducted by Carroll, et al. (1999), who evaluated the performance characteristics of three reflective materials to determine their degradation over time under controlled conditions. The materials consisted of:

- Enclosed lens (engineering grade), in which microscopic beads, bonded within the material, reflect light in a diffuse pattern toward the observer,
- Bonded reflector—typically used for pavement markings—in which exposed reflective beads are attached to the reflector backing and reflect light in a diffuse beam pattern. This pattern is wider than that reflected with the enclosed lens, and
- Prismatic retroreflector (diamond grade), in which microscopic prisms that contain three surfaces, oriented at 90º of each other, reflect light. The resulting beam pattern is more concentrated than with the enclosed lens or bonded reflectors.

The first study tested the reflectivity of the three materials over a one-year period. The materials were applied in various sizes, colors, and patterns to 14 open top hopper cars. The accumulated mileage, weather, and scheduled washings were noted. The results showed that of the three materials, the prismatic retroreflector was the most durable, maintaining 87 percent of its intensity level over the course of the year. Washing the prismatic reflectors restored its intensity to nearly its original level. The bonded lens material was the least effective of the three, with such low initial intensity levels that it did not warrant further consideration.

Because the conditions in the demonstration test did not fully simulate true railroad operations, Carroll, et al. conducted a second study to evaluate the effectiveness of the prismatic reflectors through an in-service revenue test. Reflectors were applied to four freight car fleets from two railroad companies. Three white 4- by 8-in decals were applied horizontally at the bottom of the railcar, spaced 9 ft apart, and two red-and-white 4- by36-in red-and-white delineators were applied vertically at the ends of the railcar, as shown in Figure 8.

Figure 8. Freight car reflectorization pattern used in the in-service revenue test conducted by Carroll, et al. (1999).

The pattern used was based on reflectorization research conducted on freight cars and tractor trailers. The intensity of the markers was measured periodically over a period ranging from 21 to 29 months, depending on the fleet. The results showed that the intensity of the reflectors was not significantly affected by natural environmental conditions. As in the demonstration test, washing the reflectors restored its intensity significantly to nearly its original levels. The in-service revenue test included one route for one fleet that could be used to measure the safety impact of reflectorization by allowing a comparison of the incident rate for vehicles running into a train before and after the application of the reflective markers. While there was very limited accident data, the comparison indicated that the number of accidents decreased from six before the in-service test to zero with the addition of reflectorization.

There was no consensus regarding the pattern in which reflective markers should be applied. To define an optimal marking system, Ford, Richards, and Hungerford (1998) conducted a series of studies to develop and evaluate marking patterns for the application of reflectorization. The first study consisted of a subjective evaluation of 11 candidate-marking systems. Eight of the marking systems were generated by a focus group of human factors and traffic experts; these are shown in Figure 9 below. These systems varied in color (fluorescent yellow, red, white, and/or orange) and distribution pattern (distributed over a relatively small area, distributed so that it outlined the shape of the railcar, or spaced uniformly over a relatively large area of the rail car side).

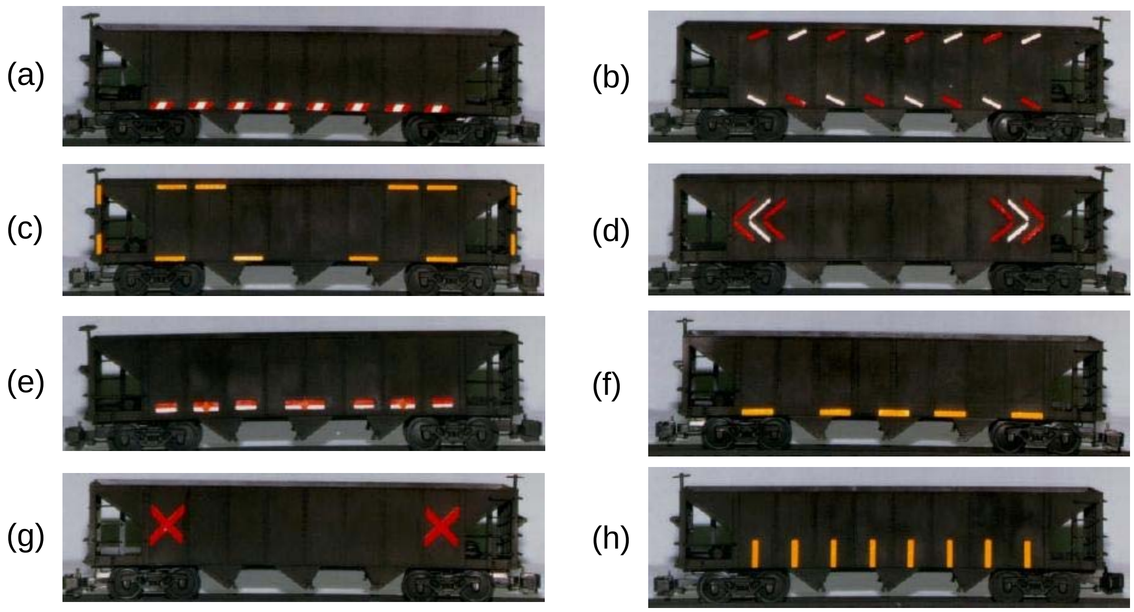


Figure 9. Marking systems generated in a focus group of human factors and traffic experts (from Ford, et al. (1998)).

The other three marking systems included the design used by Carroll, et al. (1999) in the in-service evaluation of reflective materials (shown in Figure 8), the standard design used for large trucks and tractor-trailer units (shown in Figure 10), and no reflectorization.

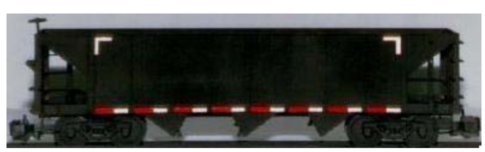


Figure 10. Standard reflectorization pattern for large trucks and tractor trailers (from Ford, et al. (1998)).

Participants completed a questionnaire in which they indicated their preference for the candidate marking systems based on their alerting effectiveness. Participants were *experts*, with traffic, railroad engineering, and human factors backgrounds, or *novices*, drivers with no special knowledge of reflectorization. The questionnaire contained three tasks:

- A paired comparison of the marking systems in which participants indicated the system in the pair which they felt would be most effective for enhancing train visibility, and

- A ranking test in which participants ranked the systems from best to worst; and
- A semantic differential evaluation, in which panelists were asked to evaluate the attributes of each marking system.

The expert group completed the questionnaire using color photographs of the marking systems. The novice group viewed actual scale models of railcars with the marking patterns under simulated nighttime conditions.

The overall results of the subjective evaluation did not indicate a preference for the use of a specific color or distribution pattern. The expert and novice groups did differ, however, in the attributes they considered in their rankings. Experts appeared to base their preferences for marking systems on color, with fluorescent yellow markings preferred the most, followed by a red-and-white combination and red-only markings. On the other hand, novices did not appear to focus on either color or pattern alone. Not surprisingly, both groups ranked the use of no reflective markings as the worst.

Although there was no clear preference for a color or a distribution pattern, Ford, et al. conducted a second study to objectively measure the effect of different marking systems on enhancing train conspicuity. Three colors and three distribution patterns were combined to create nine reflective marking systems, as shown in Figure 11 below.

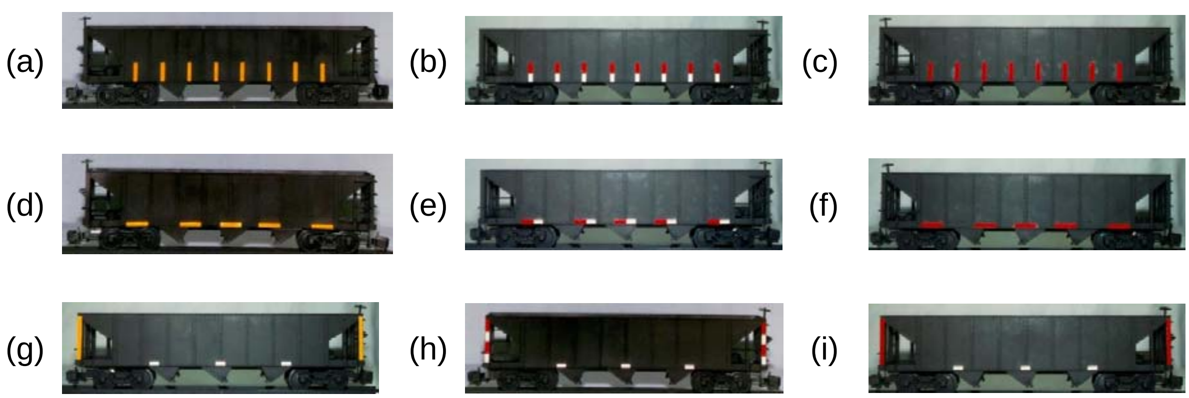


Figure 11. Marking systems for objective evaluation (from Ford, et al. (1998)).

As Figure 11 shows, the colors were yellow (the first column), red-and-white combination (the second column), and red only (the third column). The three distribution patterns consisted of a *fence* pattern of vertical markings along the side sill of the car (the first row of Figure 11); a *dash-like* pattern of horizontal markings along the bottom side sill of the car (the second row); and the *field-test* pattern used by Carroll, et al. (1999) with vertical markings on the side stakes of the car and horizontal markings along the bottom sill of the car (the third row). A tenth marking system with no reflectorization served as a control. Participants saw slides that showed each of the marking systems applied to the side of a hopper car in simulated nighttime conditions, with each subsequent slide presenting the car at a closer distance than the previous slide. Participants indicated the point at which they could detect the marking system.

The results showed that participants detected and recognized all of the nine test reflective markings faster than the nonreflective car, and that the distribution pattern appeared to improve detection more than the color of the markings. The effectiveness of the marking system improved as the horizontal and vertical visual angles formed by the distribution pattern increased; of the three distributions, the field test pattern that outlined the shape of the rail car was most effective and the dash-like pattern the least effective. Of the three colors tested, the fluorescent yellow was the most effective for detection and recognition and the red-white color pattern was the least effective.

The benefits for reflectorization, reported by Ford, et al. (1998), were found using static images without context, outside of the actual driving scenario. In real driving conditions, various sources of information, such as road signs, other vehicles, and other lights, compete for the drivers' attention. Thus, Multer, Conti, and Sheridan (2001; see also Conti, Multer, and Sheridan, 1998) conducted a series of studies to evaluate the effectiveness of reflectorization in more realistic situations using a low-fidelity driving simulator. Because reflectorization may be used to increase the conspicuity of other vehicles, Multer, et al. also wanted to determine if drivers could discriminate between reflectorized trains and other moving reflectorized vehicles at grade crossing intersections. Discriminating between the two is important because different actions may be required. For example, drivers may be able to simply slow down to avoid a collision with a truck but must stop to avoid a collision with a train.

In the first study, participants, who were seated in front of a projection screen, viewed scenes showing a two-lane road that intersected a railroad track and another two-lane road at a 90-degree angle. Participants were positioned approximately 500 ft (152 m) from the intersections and asked to identify whether a vehicle passed through the intersection and if so, whether the vehicle was a train or a truck. The scenes varied with respect to the environmental condition (rural with no visual distracters versus urban with lighting from streets and nearby buildings), freight car type (hopper versus a flat car), and reflective pattern (outline, horizontal bars, vertical bars, variable length vertical bars, and no reflectorization). A signal detection analysis, measuring whether participants could discriminate trains from trucks, found no difference as a function of the reflective pattern used. The results did show an effect of the environmental condition, such that participants were better able to detect unreflectorized freight cars in urban environment scenes (92 percent accuracy) where illumination facilitated the task, than in rural environment scenes (85 percent accuracy) where visual cues were not sufficient.

A second study was conducted to evaluate the reflective patterns in a more naturalistic setting. In the study, participants drove a simulated car along a test course containing roadway intersections and grade crossings and were asked to identify each object in the scene. Objects consisted of other cars, lights, signs, trains, and trucks. As in the first experiment, the freight car type (hopper versus a flat car) and reflective pattern were manipulated (outline, horizontal bars, vertical bars, variable-length vertical bars, and no reflectorization). Recognition distance for trains and trucks and the recognition accuracy served as dependent measures of reflectorization's effectiveness.

The results showed that participants detected the reflectorized objects at greater distances than unreflectorized objects. Participants also detected the patterns on the hopper car at a farther distance than the flat car, but it is important to note that the hopper car also had twice the reflective material than the flat car. The effectiveness of the reflective patterns varied depending on the type of freight car. With respect to recognition distance, the vertical bar, horizontal bar, and variable length vertical bar patterns aided recognition for both flat cars and hopper cars, but the outline pattern was more effective for the hopper car than the flat car. With respect to recognition accuracy, the use of the vertical bar and variable-length vertical bar patterns resulted in less confusion regarding the vehicle type than the horizontal bar or outline patterns. The horizontal bar pattern resulted in errors in which a train was confused with a truck, and the outline bar pattern resulted in errors in which a train was confused with a truck or another car. The overall pattern of results suggests that the use of vertical bar patterns will enhance conspicuity of the train and minimize confusion with other vehicles.

The FRA acknowledged the benefits of reflectorization in 49 CFR § 224, which requires the use of reflective materials on the sides of all trains and freight cars (see *Reflectorization of Rail Freight Rolling Stock; Final Rule* for more information). The use of reflectorization in conjunction with alerting lights will provide drivers with effective visual warnings regarding the presence of a train or its approach to a grade crossing. These warnings will be informative, however, only if the driver is oriented towards the train, and thus auditory signals will also be beneficial in calling attention to approaching trains.

3.3.3 Locomotive Horn

The FRA issued 49 CFR § 222 requiring that train horns be sounded when trains approach and enter public crossings to warn drivers and pedestrians at the intersection (see *Use of Locomotive Horns at Highway-Rail Grade Crossings; Final Rule* for more information). The horn must have a minimum warning sound level of 96 dB, 100 ft (30.5 m) to the front of the train in the direction of travel. Exceptions are allowed under certain circumstances; for example, when there is no risk of injury or loss of life, when use of the horn is impractical, or when other safety measures are in place to compensate for the absence of the warning from the train horn. However, the auditory warning from a train horn is effective only if the driver detects the sound, recognizes it, and responds by taking the appropriate action. A sound must be 3 to 8 decibels (dB) above the threshold of detection to be heard, and 10 dB above the ambient noise level to attract attention (Skeiber, Mason, and Potter, 1978, as cited in NTSB, 1998). Thus, noise levels in the vehicle, the enhanced sound attention qualities of the vehicle, and characteristics of the terrain at the crossing (e.g., sound can be reflected from hard surfaces, absorbed by other surfaces, or blocked by buildings or other terrain elements) all influence the detectability of the train horn.

The potential for grade crossing accidents due to the dampening of sound is of particular concern to the NTSB. Two school bus accidents at grade crossings, one in Fox River Grove, Illinois (NTSB, 1996) and the other in Conasauga, Tennessee (NTSB, 2001), were identified in which the train horn did not provide a sufficient warning to overcome the interior noise levels and sound attenuation characteristics of the buses. In both accidents, the train horn functioned properly and was sounded well in advance of the crossings, but had limited effectiveness because the buses' doors and windows were closed, radios were played inside the buses, and the buses' ceilings were partially covered with sound attenuating panels capable of reducing sound by as much as 25dB. Audibility tests conducted as part of the investigation indicated that in one accident, the decibel level of the train horn only exceeded the ambient noise level in the driver's seat when the train was 100 ft from the crossing (1.1 seconds from impact), and in the other accident, the driver may not have heard the train horn at all (NTSB, 1996, 1998, 2001; Rosenker, 2005).

Similarly, in their analysis of 60 passive grade crossing accidents, the NTSB (1998) noted that the train horn was sounded prior to impact in 55 of the 60 cases, and 14 of the 18 cases in which the NTSB was able to interview the driver. Of these 14 accidents, only four of the drivers indicated that they heard the train horn, but two of these drivers were no longer in their car at the time of impact. Of the other 10 drivers, three indicated that they were still not aware of an approaching train prior to impact, and eight reported a combination of internal and external noises that distracted them from hearing the train horn.

Numerous research studies have varied the audibility characteristics of the train horn to better understand how to improve its effectiveness. Lerner, et al (1990) reported that the number of flutes used in the train horn influenced its detectability; systems with five flutes were more effective than systems with three flutes. More recent studies have reported similar results. Keller and Rickley (1992) measured different acoustic characteristics for three "traditional" horn systems mounted on trains—two with three flutes and one with five flutes—and one wayside horn mounted at the crossing. Acoustic measurements, collected at points along a circle centered 100 ft (30.5 m) from each horn system, indicated that the sound outputs from the three traditional horn systems were more detectable than the sound output from the wayside horn. Of the three traditional horn systems, the five-flute signal created a broadband signal that was more effective at higher frequencies than signals from the three-flute systems. Because background noise in vehicles and from communities rarely contains high frequency sounds, Keller and Rickley concluded that the five-flute system was more likely to attract drivers' attention than three-flute systems. While Keller and Rickley based their recommendations for the mounting location of traditional horn systems on measurements collected in a static environment, sound level measurements from moving trains have produced similar results. English and his colleagues compared the acoustic spectrum of three-flute and five-flute horn systems not only in a stationary environment but also when used on moving freight, commuter, and passenger trains (English, et al., 2003; English and Moore, 2004). The additional flutes broadened the sound spectrum, improving the detectability of the train horn.

The audibility of the horn also varies depending on its location and for the wayside horn, its orientation. Traditional horn systems placed in front and as high as possible on the train produced maximum sound output towards the front of the train in both static (Keller and Rickley, 1992) and dynamic (English, et al., 2003; English and Moore, 2004) field tests. In fact, as train speed increased, sound output to the front of the train from horns mounted in other locations (e.g., towards the middle of the train, behind the engine exhaust hood, or recessed in a well) deteriorated. The wayside horn, which was stationary, directed most of its sound energy forward, so mounting the horn to face oncoming traffic would maximize its audibility (Keller and Rickley, 1992).

The frequency of the horn may also play a role. English, et al. (2003) found that participants detected mid-frequency signals better than signals at other frequencies when they compared pure-tone signals spanning eight different frequencies at six intensity levels relative to background noise. Detection of signals at higher frequencies was more vulnerable to masking whereas signals at lower frequencies were less audible. In particular, English et al. reported a "sweet spot" at 562 hertz (Hz), where detection rates were highest.

The effects of the various acoustic characteristics of the train horn may be interactive rather than additive. Melnik, Russo, and Popkin (2006) examined the relative contributions of the number of flutes (three-flute versus five-flute systems) and frequency (with and without a 562 Hz tone) on the detectability of the sound. Participants performed a tracking task to simulate the cognitive demands of driving while detecting signals (the sounds of a train horn) against background noise. The results showed that participants most easily detected a five-horn system with a 562 Hz tone, but surprisingly, there was no main effect either for the number of flutes or for the inclusion of a horn with a 562 Hz tone.

Although sounding the train horn has important safety benefits, communities near grade crossings have complained that the noise negatively impacts their quality of life. In fact, acoustic data, collected from trains at six grade crossings in Jacksonville, Florida, showed that sound levels at locations less than 200 ft (61 m) from the crossing were unacceptable for an outdoor residential noise environment, based on criteria set forth by the U.S. Department of Housing and Urban Development (Rapoza, Raslear, and Rickley, 1999). Several states and communities issued whistle bans to pacify residents, but analyses have shown that these whistle bans increased the rate of grade crossing accidents and incidents (this topic will be discussed in more detail in section 6.1).

One alternative is the use of a wayside horn, mounted at the crossing, to provide a similar audible warning as the train horn but minimize the noise impact on surrounding communities. Keller and Rickley (1992) noted that the wayside horn was less detectable than traditional horn systems in a laboratory evaluation, but they did not examine its impact on driver behavior. That is, the "detectability" of a sound may not be defined solely by auditory characteristics (Rapoza, et al., 1999). As a result, several studies have evaluated the effectiveness of the wayside horn on improving compliance and have examined its benefits to communities living near grade crossings.

In one study, Multer and Rapoza (1998) examined the effectiveness of wayside horns mounted at three gated grade crossings in Gering, Nebraska. In 1995, driver behavior at two of the three grade crossings was videotaped for a period of 12 weeks before and after the installation of the wayside horn. Data collected consisted of the frequency with which drivers violated the grade crossing as the gate arms were descending (Type 1 violations), the frequency with which drivers violated the gated crossing after the gate arms had completely descended (Type 2 violations), the warning time at the crossing, the time to collision defined as the time between a driver crossing the tracks and the train's arrival at the crossing, and the violation time defined as the time between the gates descent and the driver's arrival at the grade crossing. The results indicated that the use of the wayside horn did not decrease safety at the crossing relative to the train horn. In fact, the number of Type 1 violations was significantly lower with the wayside horn than with the train horn. However, this result should be considered in light of the fact that the train horn had a false activation rate that was two times higher than the wayside horn. As a result, drivers' perception that the train horn was not reliable or that a train was not in close proximity may have led to the increased rate of Type 1 violations observed. There was no difference in the number of Type 2 violations, time to collision, or violation times attributable to the horn systems.

Multer and Rapoza also conducted telephone surveys of residents in nearby communities before and after the installation of the wayside horn to examine its impact on their quality of life. The "before" survey addressed the impact of the train horn on noise in the community, and the "after" survey, conducted one-year later, measured the impact of the wayside horn. Participants living within 3,200 ft (975 m) from the tracks were asked questions that addressed how frequently they heard the auditory warning, how they were affected by the noise, what types of activity the noise interfered with, and what measures they took to minimize the negative effects of the noise. As part of the study, acoustic measurements of the loudness and frequency distribution of the train horn and wayside horn were collected at 14 sites around the city. The survey results showed that the use of the wayside horn had a positive impact. Fewer residents were highly annoyed with the noise from the wayside horn than with the noise from the train horn. Additionally, the wayside horn interfered less with activities inside or outside the home and required fewer actions to minimize the noise impact. The acoustic measurements indicated that the wayside horn was approximately 13 dB quieter than the train horn at peak sound levels, and in fact, the wayside horn did not meet the minimum sound level required of train horns. The acoustic data also indicated that the wayside horn impacted residents over a smaller geographical area than the train horn; the locations where the wayside horn had a significant noise impact were limited to locations within 100 ft (30.5 m) of the wayside horn, whereas the locations where the train horn had a significant noise impact extended out to 1,000 ft (305 m) from the track. Interestingly, the locations of those residents who were highly annoyed by the noise were distributed throughout the geographical area covered in the survey and not related to the proximity to the track or grade crossing. This finding may be the result of obstructions and/or environmental factors that distort the relationship between the sound level and distance from the noise source.

Gent, Logan, and Evans (2000) conducted a similar study in Ames, Iowa. They evaluated the impact of the wayside horn through noise level readings before and after the installation of wayside horns at three grade crossings and surveys of residents living near the crossing, drivers stopped for trains at the crossing and for train engineers. The noise level readings showed that the wayside horn system had a lower volume than the train horn at all locations. Noise contour maps depicting the geographical impact of the horn systems showed that the wayside horn reduced the geographical area affected by the noise than the train horn. Subjective data was positive regarding the use of the wayside horn. A survey of residents two months before and after the installation of the wayside horn found that residents felt the wayside horn improved their quality of life; 77 percent of residents indicated that train horn had a negative impact in the before study, whereas only 3 percent felt that the wayside horn had a negative impact. Drivers indicated that they preferred the wayside horn system compared to the train horns, with 22 percent of drivers indicating that the wayside horn was their first alert to an approaching train. Feedback from the locomotive engineers indicated that the majority considered the use of the wayside horn system at the crossing as being just as safe, if not safer, than with the train horns.

The acoustic data collected in the field by Multer and Rapoza (1998) and Gent, et al. (2000) and in the laboratory by Keller and Rickley (1992) all indicated that the wayside horn systems was less audible than the train horn. The wayside horn systems evaluated in these three studies were developed by Railroad Controls Limited (RCL). On the basis of the results, RCL increased the warning volume of the wayside horn and added low frequency tones to better match characteristics of the traditional train horn (Mike Fann & Associates, 2000). Two field tests of this improved horn system were conducted: one by the City of Richardson, Texas, and the other in the Village of Mundelein, Illinois. In Richardson, Texas, noise level readings were collected at different locations around the grade crossing at which a wayside horn was located and compared to that obtained with the train horn. The results showed that while the sound level from the wayside horn was greater than or equal to the sound from the train horn at a distance of 100 ft (30.5 m) from the crossing, sound levels in the surrounding neighborhood decreased relative to that obtained with the train horn. In fact, the number of homes experiencing noise levels above 90 dB dropped from 38 homes to two (P.B. Farradyne, Inc., 2001).

In Mundelein, Illinois, wayside horn systems were installed at all 9 grade crossings in or near the Village and evaluated in a field study patterned after Multer and Rapoza (1998) and Gent, et al.

(2000). Video cameras at three crossings recorded drivers for 3 months before and after the installation of the wayside horn systems. Analysis compared the rates of Type 1 and Type 2 violations, as defined in Multer and Rapoza to be the frequency with which drivers violated the grade crossing as the gate arms were descending and the frequency with which drivers violated the gated crossing after the gate arms had completely descended, respectively, before and after the installation of the wayside horn systems. The noise impact of the wayside horn was measured by comparing acoustic measurements of the wayside horn with that of the traditional train horn at nine locations throughout the Village. Finally, residents and train engineers were surveyed regarding their perception of the effectiveness of the system.

The results from the driver observations showed that the overall violation rate declined significantly by 68 percent after installation of the wayside horn from 3.53 per 100 gate closings to 1.12 per 100 gate closings. The rate of Type 1 violations dropped by 74 percent, from 358, with the train horn, to 93 violations after the installation of the wayside horn. The rate of Type 2 violations dropped by 56 percent, from nine with the train horn to four with the wayside horn.

Measurements of the sound level of the two horn systems indicated the sound level of the wayside horn was greater than or equal to the sound of the train horn as the driver was approaching the grade crossing, similar to that found in Richardson, Texas (P.B. Farradyne, Inc., 2001). The train horn was only louder than the wayside horn when the train was at the crossing. The acoustic results also showed that the wayside horn impacted fewer residents than the train horn; the wayside horn affected 85 percent less area than the train horn at the highest decibel levels. Residents who benefited the most from the installation of the wayside horn were those living at angles 45º or greater from the horn. However, in some areas (in particular, those locations in a direct line of the wayside horn), the sound level remained constant or increased. The results of the acoustic analysis were reflected in the results of resident surveys addressing quality-of-life issues. Residents generally found the wayside horn less annoying than the train horn, unless they lived close to or in a direct line with the wayside horn. Both residents and train engineers indicated that they perceived the crossing to be as safe as or safer with the wayside horn than they had been with the train horn. Most of the train engineers indicated that they had not noticed a difference in driver behavior, although most also admitted to sounding the train horn occasionally when they felt that the wayside horn as not working or believed that the train horn was needed (e.g., when pedestrians and bicyclists were crossing in front of approaching trains) (Raub, Lucke, and Thunder, 2003; Thunder, Raub, and Lucke, 2003).

The studies discussed above only examined the effect of the wayside horn on driver behavior in the short-term immediately after its installation. To determine the longer-term effects of the wayside horn, Roop (2000) conducted a follow-on study to Multer and Rapoza (1998), 5-years after the wayside horn was installed in Gering, Nebraska, and data on driver compliance was first collected. To determine if there was a long-term change in driver compliance, determined by the number of Type 1 and 2 violations, driver behavior was video recorded at one of the three grade crossings in Gering with the wayside horn. The results showed an increase in the rate of Type 1 violations (i.e., the number of drivers who violated the crossing as the gate arms were descending) relative to that observed by Multer and Rapoza in the initial post-test period and no difference in the rate of Type 2 violations. Whereas the rate of Type 1 violations rose in the time following system implementation, it is important to note that the violation rate was similar to that observed with the train horn. It is possible that the initial drop in Type 1 violations observed by Multer and Rapoza was attributable to driver unfamiliarity with the sound intensity of the wayside horn, so that drivers using auditory intensity as a cue to train proximity perceived the train as being close to the grade crossing upon hearing the wayside horn. Over time, as drivers became more familiar with the wayside horn, they learned that auditory intensity was no longer an effective indicator of train distance and were less responsive to its alert.

3.3.4 Summary

In order to increase the conspicuity of trains at or approaching grade crossings, the FRA requires equipping trains with alerting light systems (49 CFR § 229), using reflective markings (49 CFR § 224), and sounding the train horn (49 CFR § 222 and 229). The results of field tests have shown the effectiveness of alerting lights; participants detected trains equipped with alerting lights at further distances than those with the headlight alone and were less likely to overestimate its arrival time to the crossing (Carroll, et al., 1995). Additionally, the results of accident analyses have found significant reductions in the number of incidents and fatalities attributable to the use of alerting lights (Mok and Savage, 2005).

Improvements in reflective materials renewed interest in the use of reflectorization to enhance train conspicuity. The results of demonstration tests and in-service revenue tests showed that prismatic, diamond grade reflectors were most durable in maintaining their intensity level over time, and simple washing of the reflectors restored intensity to original levels (Carroll, et al., 1999). Participants detected trains with reflective markers at greater distances than nonreflectorized trains (Ford, et al., 1998; Multer, et al., 2001), and accident data, while limited, suggested that reflectorization reduced the number of grade crossing incidents and accidents (Carroll, et al., 1999). In applying reflective markings to trains, the distribution pattern may contribute more to the effectiveness of reflectorization than the color of the markings. No study has identified an optimal pattern, but Ford, et al. (1998) found that the effectiveness of the markings improved the larger the horizontal and visual angle formed by the distribution pattern. Because reflectorization is also used to enhance the conspicuity of other vehicles, it will be important to select a pattern that minimizes confusion. In particular, reflective patterns used on trucks in revenue service consist primarily of horizontal bars located along the bottom of the vehicle, so reflective patterns for trains that contain vertical bars may be more effective at facilitating train-truck discriminability than patterns consisting solely of horizontal markings (Multer, et al., 2001).

The train horn provides an auditory warning to alert drivers and pedestrians of its approach to a grade crossing. The audibility of the train horn is most effective when it is mounted at the front of the train; sound output from horns mounted at other locations deteriorates with increasing train speed (Keller and Rickely, 1992; English and Moore, 2004). However, the train horn is effective only if it is detected, and the dampening of sound is of particular concern (NTSB, 1998). At the same time, communities located near grade crossings have complained of the noise impact from the train horn. The use of a wayside horn mounted at the crossing to alert the driver when a train is approaching is promising. Observations of driver behavior indicated that the wayside horn does not decrease safety. In the short-term (i.e., immediately after its installation), observations of driver behavior reported a decrease in the rate of violations with the wayside horn as compared to the train horn as the gate arms were descending (Multer and Rapoza, 1998; Raub, et al., 2003), although this effect did not last in the long-term (Roop, 2000). Several studies have noted the impact of the wayside horn on reducing community noise; noise level readings collected before and after the installations of wayside horns showed that the wayside horn impacted residents over a smaller geographical area, while still providing a sound level greater than or equal to the train horn on drivers' approach to the crossing (P.B. Farradyne, Inc., 2001; Thunder, et al., 2003).

This section focused primarily on improvements to the grade crossing environment to better convey the driver action required and facilitate detection and recognition of the grade crossing and the presence or approach of trains. However, these improvements to the grade crossing alone may be insufficient. To be truly effective, any measure must engage the driver. Thus, characteristics inherent to the driver that influence compliance must be considered.

4 Personnel Subsystem (Driver)

Driver exposure to a highway-rail grade crossing accident is increasing as the number of total vehicle miles and train miles per railway increases. Warning devices at highway-rail intersections offer some protection by alerting the driver to the presence of a crossing (e.g., with a railroad advance sign on the approach to the crossing and a crossbuck at the crossing) and the presence of a train (e.g., the train horn or active warning devices, such as flashing lights and/or automatic gates). However, some drivers simply choose not to comply. In fact, in most grade crossing accidents, a clear warning and adequate visibility of the train's approach was available (Leibowitz, 1985). Thus, other factors influencing a drivers' behavior at grade crossings must be considered.

Drivers' actions at grade crossings are based not only on their perception and comprehension of the information available at the crossing but also by their motivations. Thus, limitations in *driving skill* that lead to error or characteristics of *driving style* (i.e., intention) contribute to noncompliance. With respect to the former, age-related decrements in perception and cognition, lack of experience, driver distractions, or impairment all influence the driver's skill level. With respect to the latter, the driver's biases and attitudes towards grade crossings and compliance determines driving style; for example, the driver's expectancy of trains, perceived costs of compliance, and perception of risk. Additionally, because one's character is reflected in one's driving style, personality differences attributable to gender and changes attributable to age and maturity must also be considered.

This section addresses decrements in driving skill and the contributions of driving style to overall driving performance. While studies examining these factors on behavior in the grade crossing situation are limited, much research has been conducted in the context of the general driving situation and provide additional insight into driver behavior. Implications of this research related to the grade crossing situation will be noted.

4.1 Driving Skill

Driving skill addresses performance limits in detecting the train or the crossing, estimating the train's arrival time, and executing the appropriate action. Lerner, et al. (1990) discussed much of the research examining perceptual limitations influencing driving performance, and little research has been conducted since the publication of their report addressing countermeasures for improving the perceptual process. Extensive research exists, however, examining factors that limit driving skill and understanding the performance decrements due to aging, lack of experience, driver distractions, and alcohol/drug use or fatigue. Each of these topics is addressed below.

4.1.1 Age

An analysis of accidents in the NHTSA Fatal Accident Reporting System (FARS) from 1975 to 1992 showed that drivers between the ages of 25 and 34 years old accounted for the greatest percentage (24 percent) of fatal grade crossing crashes, followed by drivers between 16 and 20 years old (17 percent). In contrast, drivers 65 to 74 years old accounted for only 7 percent of fatal grade crossing crashes, and drivers over the age of 74 years old accounted for approximately 5 percent of fatal grade crossing crashes (Klein, Morgan, and Weiner, 1994). Alhtough the FARS data suggest that older adults are not at an increased crash risk relative to other drivers, the data do not reflect exposure level. When examining statistics for highway traffic accidents, older adults appeared to be the safest age group on the road on a licensed driver basis, but when crash rates were calculated as a function of exposure (defined by miles traveled), older drivers were at an increased crash risk. In fact, while the average rate of fatalities in highway accidents was 2 per 1,000 crashes, drivers between the ages of 65 to 74 had a fatality rate of 3.2, drivers aged 75 to 84 had a fatality rate of 5.3, and those 85 and older had a rate of 8.6 (Potts, et al., 2000).

The causes for accidents at different ages are attributable to different factors related to one's skill and ability. Higher accident rates for younger drivers may be due to a lack of knowledge and driving proficiency. In fact, younger drivers tend to underestimate the risk of potential driving hazards. Groeger and Chapman (1996) measured driving skill for younger and older drivers using a hazard perception test in which drivers rated the perceived danger in videotaped driving scenes. The results showed that drivers generally evaluated the driving situation as a function of the perceived difficulties in driving, the dangers observed, and the uniqueness of the situations. Younger drivers were more likely than are older drivers to perceive the danger in the driving scenes, but underestimated the risk of these dangers relative to older drivers.

On the other hand, older drivers suffer from impairments in information processing. Crashes by elderly drivers have been attributable to degradations in basic visual acuity and failure to respond to the rapidly changing traffic situation (Ball and Owsley, 1991; Elander, French, and West, 1993; Viano, 1990). In particular, visual detection declines among older drivers, and this problem is exacerbated at night. An analysis of grade crossing accidents in Texas from 1992 to 1994 found that the frequency of elderly drivers involved in a grade crossing accident at night was higher than their involvement in all other crashes at night (Fambro, et al., 1995).

Staplin, Lococo, Sim, and Drapcho (1989) examined age-related differences in visual performance for young to middle-aged drivers and older drivers and their effect on driving. *Young to middle-aged drivers* ranged from 18 to 49 years old, and *older drivers* ranged in age from 65 to 80 years old. Visual performance was assessed using a contrast sensitivity test. Participants, presented with a Landolt-C (the target) in one of eight orientations, detected the orientation of the gap. The target was shown in varying levels of intensity. Once participants completed the contrast sensitivity test, they performed two driving-related tasks. The first was a pavement-marking task, in which participants saw nighttime roadway scenes with right- and left-bearing curves and indicated whether they should steer right or left based on pavement markings superimposed in the scene. The level of glare in the scene and the brightness of the pavement marking with respect to the background were manipulated. The second task measured the participant's ability to read signs presented in different text sizes, text colors, and background colors. Three types of signs were shown: *guidance* signs printed in white lettering on a green background, *warning* signs printed with black lettering on a yellow background, and *regulatory* signs printed with black lettering on a white background.

Young to middle-aged drivers had higher contrast sensitivity and performed better on the two driving-related tasks than the older drivers. Visual contrast sensitivity differed between the age groups at the lowest level of illumination, with young to middle-aged drivers better able to detect the orientation of the Landolt-C at lower contrasts than are older drivers. This diminished visual acuity affected performance in detecting pavement markings and reading road signs. In the pavement-marking task, older drivers required a level of contrast approximately 20 percent greater than young to middle-age drivers. Although glare increased the response time in both groups relative to the no glare condition, it did so more for the older drivers than the young to middle-aged drivers. In the sign task, young to middle-aged drivers read the sign information at smaller mean letter sizes relative to the older drivers. The results highlight the need for more contrast in the roadway environment to accommodate older drivers in order for pavement markings and road signs to be effective for all drivers.

Older drivers may also require more time to make the decision to stop or proceed and execute that action (Staplin and Fisk, 1991). Ranney and Pulling (1990) compared performance on a driving test for young drivers, ranging in age 30 to 51, to that for older drivers, ranging in age from 74 to 83. The driving test involved three 30-minute trips around a closed course. Each trip consisted of up to 20 laps around the course, during which participants responded to variable-timed traffic signals and route information presented on traffic signs. A secondary task required participants to avoid moving and stationary hazards and respond to regulatory signs. Driver performance was measured both subjectively by in-car raters and objectively. After completing the driving task, participants completed a series of laboratory tasks that measured cognitive factors such as perceptual style, response speed, short-term memory, selective attention, efficiency of attention switching, reaction time, and risk taking. Subjective performance ratings by in-car observers on the driving task showed that young drivers received higher ratings than older drivers for decision speed, gap execution, route selection, and comprehension of task instructions. Objective performance results indicated that older drivers had longer lap times and exhibited poorer vehicle control than the young drivers. Additionally, older drivers were more likely to make judgment errors regarding acceptable gap sizes by selecting gaps that were too small or avoiding gaps that were equal or greater than the width of the car. Older drivers also had a higher number of gap execution errors and struck objects or moved at an excessively slow speed. The results of the laboratory cognitive tasks were similar to the ratings and objective performance results; older drivers showed poorer performance relative to younger drivers. In particular, complex tasks that required the use of short-term memory and attention switching between two sources of information showed large performance differences between young and older drivers.

Ranney and Pulling measured drivers' gap judgments statically, without moving vehicles. In a general driving situation, gap judgments require integration of speed and distance information. The accuracy of these calculations has often been evaluated in the highway-driving domain by measuring the time between two successive vehicles accepted by drivers (e.g., see Ebbesen, Parker, and Konecni, 1977). Results of these evaluations showed that the accuracy of these gap estimations improved with experience but declined with age. An analysis of overtaking accidents in England showed that the most frequent error, passing a vehicle when it was turning right, was committed primarily by drivers under 25 years old and those over 60 years old. Errors committed by younger drivers were the result of a failure of attention to the driving environment combined with lack of skill, such as losing control after overtaking the car. Older drivers, on the other hand, failed to wait long enough when turning onto a road or waited too long when turning off a road (Clarke, Forsyth, and Wright, 1998; Clarke, Ward, and Jones, 1998).

Although most of the perceptual decrements related to driving are visual, impairments to the auditory system will reduce the alerting effectiveness of the train horn. Approximately 30 percent of persons aged 65 or older have some sort of hearing impairment (Department of Health and Human Services, 2005). This hearing loss increases one's accident risk. Accident records showed that completely deaf males were involved in more accidents than non-deaf males, although their exposure level was also higher (no difference for female drivers was noted). Since the majority of older drivers are not completely deaf, of more relevance is accident data suggesting that drivers wearing hearing aids were involved in more accidents than their non-hearing-impaired counterparts. Drivers with visual loss in addition to hearing loss had an even worse driving record than those with hearing loss only (Janke, 1994).

Staplin, et al. (2001) provides suggestions for compensating for age-related decrements at passive grade crossings. In addition to reflectorization of the crossbuck post, additional signs that indicate driver action should be included (e.g., a yield sign or "Look for Trains") and reflectorized. At illuminated crossings, the luminaries should be aligned toward the track rather than the road. Finally, at non-illuminated rural grade crossings, delineators should be used from the advanced warning sign to the crossbuck to indicate the approach to the crossing.

4.1.2 Experience

As driving experience increases, the likelihood of being in an accident decreases. Maycock, Lockwood, and Lester (1991) asked drivers in the United Kingdom to provide information on their accident involvement over the last 3 years, or for new drivers, their accident involvement since they started driving. The results showed that one's likelihood of being in an accident decreased as a function of age and experience, and this change in accident liability was greater for younger drivers than for older drivers, suggesting a steep learning curve for new drivers.

Much of the learning process may be in determining an efficient visual search strategy. McKenna and Crick (1991) noted that drivers' ability to detect hazards improves with experience. In their study, participants watched videos of various road and traffic situations and were asked to detect hazards by responding with a button press. Participants consisted of novice drivers with 1–3 years of driving experience, experienced drivers with a mean driving experience of 22 years, and expert drivers who were driving instructors with a mean driving experience of 22 years. The results of the task showed that expert drivers responded to hazards the fastest and novice drivers the slowest. Expert drivers detected hazards from a greater distance than novice drivers did and missed fewer incidents. The results suggest that expert drivers were better able to scan the entire driving scene because of their increased experience whereas novice drivers tended to focus on areas close to their vehicles. The expert drivers also performed better than the experienced group, despite the same number of years of driving experience. Because the expert group was exposed to many weeks of intensive training, some of which was aimed at improving their hazard perception, the results suggest that this skill can be improved with additional instruction.

Crundall and Underwood (1998) noted differences in visual sampling as a function of experience. Participants, wearing an eye tracker, drove a 20-minute route on three road types that imposed different levels of visual demand: a rural single lane road; a suburban road through a small village; and a busy road with two lanes of forward moving traffic with traffic merging on the left. Novice drivers had 2 years or less of driving experience and experienced drivers had approximately nine years. Experienced drivers adapted their sampling strategies by looking at more locations but spending less time at each location for the visually demanding roads (i.e., the busy road and the suburban road), but novice drivers did not.

Similar results were observed by Pradhan, et al. (2005) when they compared novice drivers' scanning behavior to that of more experienced drivers in their abilities to acquire and respond to risk-relevant information. Novice drivers who had less than six months of driving experience and two groups of experienced drivers (young drivers between 19–24 years old and older drivers between 60–75 years old) navigated through scenarios in a driving simulator. The scenarios presented drivers with risk-relevant information such as warning signs, traffic control devices, pedestrians, and other vehicles. Behavior was measured through eye movements to determine where drivers looked and through observations of driver actions, such as failing to stop at a stop sign. The results showed that experienced drivers engaged in behaviors that indicated their recognition of the risk potential in the scenarios significantly more than novice drivers, with older, experienced drivers engaging in these behaviors significantly more than younger, experienced drivers. The scanning behavior of novice drivers indicated their failure to obtain risk-relevant information and as a consequence, they were unable to respond appropriately.

Taken together, these results suggest that detection of grade crossings and trains will improve with driving experience. The countermeasures proposed by Staplin, et al. (2001) to call older drivers' attention to passive grade crossings might also be effective for the inexperienced driver. The important point to note is that with increased experience, noncompliance with grade crossings due to a lack of skill will decrease.

4.1.3 Driver Distractions

Distractions are a common component in driving. The NTSB (1998) reported that driver distractions were the primary cause or a contributing factor in 20 percent of the passive grade crossing accidents analyzed. Internal distractions included adjusting the stereo system or talking to passengers. Traffic-related distractions included road intersections and traffic, which drew attention away from the grade crossing.

Little research has been conducted specifically examining the role driver distractions cause in grade crossing accidents. More data is available regarding the role of distractions in the general driving situation. Stutts, et al. (2005) collected video data of behavior inside the vehicle and found that drivers engaged one or more potentially distracting activities 14.5 percent of the time when the vehicles were moving. The activities drivers engaged in differed depending on whether the vehicle was stopped or moving, suggesting that drivers chose to engage in certain activities at "safer" times during driving.

In a larger study of in-vehicle driver behavior, 100 drivers in the northern Virginia/Washington DC Metro area were observed for 1 year to better understand the cause of crashes and develop effective countermeasures to prevent them. One hundred vehicles were equipped with video cameras and sensor systems to monitor events in and around the vehicle. In the 1-year observation period, drivers in the study were involved in 82 crashes (defined as any contact between the vehicle and another vehicle, object, person, or animal), 761 near crashes (any conflict situation requiring a rapid evasive maneuver), and 8,295 incidents (a conflict requiring an evasive maneuver but not as serious as a near crash). Driver inattention was measured by secondary task distractions, inattention to the forward roadway, drowsiness, and other non-driving related eye glances. Of these four categories, secondary task distractions contributed to the highest percentage of crash and near crash events. In particular, use of wireless devices, such as cell phones and personal digital assistants, accounted for the highest frequency of distractions followed by passenger-related inattention (e.g., conversations) and internal distractions (Dingus, et al., 2006; Neale, et al., 2005).

The results addressing the impact of distractions on highway driving suggest that distractions could have a significant impact on driver behavior at grade crossings. Drivers distracted by another task may not realize they are approaching a grade crossing (particularly a passive crossing), fail to attend to activated warning devices, or fail to detect an approaching train. The distracted driver may be especially susceptible to the hazards at grade crossings; however, the amount of increased risk is not known.

4.1.4 Driver Impairment

The roles of alcohol use and fatigue have been noted as contributing factors to highway accidents, and it is believed that they play a role in a significant number of grade crossing accidents as well (Lerner, et al., 1990). In fact, an accident analysis of grade crossing accidents in Texas from 1992 to 1994 by Fambro, et al. (1995) showed that driver impairment as a result of alcohol use, drugs, medication, or fatigue accounted for 14 percent of crashes in that time period. Although these factors have been studied extensively to measure their effects on human performance, little information was available specifically regarding their impact on driver performance at grade crossings.

Alcohol Use

With respect to alcohol use, the accident analysis conducted by Klein, et al. (1994) reported that the rate of alcohol involvement in grade crossing crashes (67 percent) from 1975 to 1992 was similar to the rate of alcohol involvement in highway crashes (66 percent) for that same time period. A more recent comparison was not available. An examination of highway statistics showed that in 2004, alcohol use (defined by a blood-alcohol level of 0.10 or greater) contributed to 7 percent of all traffic crashes and 39 percent of the total traffic fatalities, a 2.4 percent decrease from 2003 and a 4 percent reduction in the ten-year period from 1994. The incidence of alcohol-related crashes was five times greater at night (16 percent) than during the day (3 percent). Additionally, young drivers were more likely to be involved in an alcohol-related crash than older drivers; drivers aged 21 to 24 years old accounted for the highest percentage (32 percent) of fatal crashes followed by drivers aged 25 to 34 (27 percent) (NHTSA, 2005).

While the legal blood-alcohol level nationwide is 0.01, driving skills are impaired at moderate departures from a blood-alcohol level of zero. In a review of the literature from 1981 to 1997 regarding the effects of alcohol use on driving related skills, Moskowitz and Fiorentino (2000) reported that one’s ability to divide attention to perform two concurrent tasks may become impaired at a blood-alcohol level as low as 0.005, the ability to track an object becomes impaired with a blood-alcohol level of 0.02, perceptual abilities are impaired at a blood-alcohol level of 0.03, and reaction time at levels of 0.04.

Several countermeasures have been implemented to reduce the rate of alcohol-related crashes. Many of these countermeasures consisted of legislation addressing the legal blood-alcohol level. A majority of states, the District of Columbia, and Puerto Rico lowered the legal blood-alcohol level from 0.10 to 0.08 and noted declines in alcohol-related fatal crashes as a result. Additionally, zero-tolerance laws setting the legal blood-alcohol level between 0.00 to 0.02 for drivers younger than 21 years old have led to a 20 percent decline in fatal crashes for drivers in that age group. In Maine, a law lowering the legal blood alcohol level to 0.05 for drivers previously convicted of driving under the influence (DUI) significantly reduced the number of fatal crashes for this group.

Legislation has also provided for immediate punishment of DUI offenses. Laws allowing for immediate license suspension at the time of arrest for first-time and repeat DUI offenders reduced alcohol-related fatal crashes and repeat DUI offenses. However, up to 75 percent of drivers with suspended licenses continued to drive. Also, impounding or immobilizing vehicles for repeat DUI offenders resulted in lower recidivism rates.

Public information campaigns, such as high school and college prevention programs and community initiatives to prevent drinking and driving, have also been successful in reducing the number of fatal crashes, the number of alcohol-related fatal crashes, and the number of traffic injuries. Additionally, interventions in emergency rooms with patients injured in alcohol-related crashes reduced future drinking and emergency room re-admission. Finally, breath alcohol ignition interlock devices that prevent vehicle operation if the drivers' blood-alcohol level is above a predetermined level has lowered the recidivism rate, although the long-term effects on driver behavior after the interlocks have been removed, are unclear (National Institute on Alcohol Abuse and Alcoholism, 2001).

Fatigue

Fatigue has a similar effect on driving skill as alcohol use, resulting in deficiencies in information processing, reduced vigilance, and slower reaction times. While it is not possible to attribute with certainty the cause of a crash to drowsy driving, NHTSA estimates that 100,000 police-reported crashes are attributable to driver fatigue. The National Sleep Foundation's 2005 Sleep in America poll reported that 60 percent of adult drivers indicated that they have driven while fatigued in the past year; this is a significant increase of approximately 8 percent from the past three years. Additionally, 37 percent of drivers indicated that they have nodded off or fallen asleep while at the wheel, and of these drivers, 13 percent indicated that they did so at least once a month. In fact, 4 percent indicated that they had an accident or near accident attributable to drowsy driving (National Sleep Foundation, 2005). Dingus, et al. (2006) reported that drowsiness was a contributing factor in 12 percent of crashes and 10 percent of near crashes in their observations of 100 drivers over 1-year; this rate is higher than the 2–4 percent estimate for fatigue-related accidents in existing crash databases.

Most drowsy driving accidents occurred in the nighttime, after midnight, with a smaller peak in the midafternoon. Three driver groups are especially at risk. First are young drivers, and in particular males, between the ages of 16 and 29 years old. Accident data indicated that young drivers under 30 years old accounted for almost 66 percent of fatigue-related crashes and were four times more likely to be involved in such a crash than drivers over 30. Additionally, male drivers were involved in 75 percent of crashes in which the driver fell asleep at the wheel, and were 5 times more likely than females to be involved in a fatigue-related crash. The second at-risk group is shift workers, who because of continuous disruptions in their sleep schedule, are at an increased risk of sleepiness. Rotating shifts, such as working four or more day or evening shifts and four night shifts or more within a 1-month period, are particularly disrupting to sleep. In fact, studies of nurses have found that those who work a rotating schedule reported more vehicle, on-the job, and near-miss accidents than nurses on other schedules, and 95 percent of night nurses working a 12-hour shirt reported having had an accident or near-miss while driving home from work. Finally, a third at-risk group is those with untreated sleep disorders, such as sleep apnea and narcolepsy. Note that while these sleep conditions put the drivers at risk for drowsy-driving accidents, there is no link between these sleep disorders and impaired driving (NHTSA, 1997).

Countermeasures include getting a sufficient amount of sleep, avoiding alcohol when sleepy, and limiting driving between the hours of midnight to 6 a.m. When a driver becomes sleepy, it is important to stop driving and take a short nap or consume caffeine equivalent to two cups of coffee. Other steps to improve alertness when sleepy, such as listening to the radio or opening a window, have not been sufficiently demonstrated. The use of rumble strips, placed on high-speed rural roads, reduced the number of crashes in which a drowsy driver steered a vehicle off road, but no study has evaluated their effectiveness in preventing drowsy driving crashes in other situations. Public information campaigns that target the at-risk groups may be beneficial (NHTSA, 1997).

4.2 Driving Style

One's choice of driving style is a reflection of drivers' perception of the dangers at grade crossings. In general, drivers have a low expectancy for encountering a train at a grade crossing. The decision to comply is often weighed with the "costs" for doing so. For example, if drivers are in a hurry, they may be tempted to ignore the flashing lights. In fact, over 80 percent of grade crossing fatalities occur at active crossings because drivers ignored the warning device (Savage, 2006).

The discussion regarding the effect of driving style on grade crossing behavior focuses on the role of expectancy, the perceived costs for compliance, and risk perception and risk-taking behavior. These three factors will be moderated by gender differences and age, as addressed below. Proposed countermeasures for changing driving style are also discussed, but it is important to note that driving style is an expression of one's personality, so it will be more difficult to change than driving skill.

4.2.1 Expectancy

Expectancy guides attention and determines when and where drivers look for trains. Drivers who are familiar with a crossing have an expectancy about the likelihood of encountering a train at that crossing. If expectancy is low, then the driver who is familiar with the crossing will be *less* likely to detect a train at that crossing than a driver who is unfamiliar with the crossing or a driver who frequently encounters trains at that crossing (Lerner, et al., 1990). In fact, grade crossing accidents were committed more frequently by drivers familiar with the area than unfamiliar drivers (Abraham, et al., 1998).

In general, drivers do not expect to encounter a train at a grade crossing. Minnesota residents participating in a focus group reported that while they encountered grade crossings regularly, they usually did not meet a train (Dolan, 1996). This low expectancy is reinforced each time the driver passes the crossing without encountering a train, and as a result, drivers tended to underestimate the frequency of a train at a crossing by a factor of two or three (NTSB, 1998). In the general driving situation, low expectancies of other vehicles were a significant factor in highway accidents (Triggs, 1988). Additionally, attention to road signs is based on perceived importance; drivers who pass warning signs frequently without being required to take any action have less motivation to use the information provided by the sign and other comparable signs (Rumar, 1990). Thus, a low expectancy and low frequency of trains at grade crossings may cause drivers to simply disregard the warning signs.

Observations of driver behavior at grade crossings have shown that many drivers fail to even look for a train and make no head movements at the crossing. Åberg (1988) reported that of 584 drivers observed at 16 active grade crossings in Sweden, 60 percent of drivers made no head movements at all. Only 25 percent of the drivers looked both ways at the crossing, 10 percent looked in the direction in which visibility was less restricted, and 5 percent looked in the direction in which visibility was more restricted. Because Åberg observed behavior at active grade crossings, it can be argued that drivers did not need to look for trains since the warning devices at the crossing would provide information regarding approaching trains. However, observations of driver looking behavior at passive grade crossings have shown similar results. In the study by Wigglesworth (2001), described in Section 3.1.1.2, the results of observations at one passive crossing indicated that 37 percent of drivers made no head movements, and the results of observations at a second crossing where visible enforcement was present, found that 44 percent of drivers made no head movements. Enhancing the conspicuity of the warning devices, advising drivers on the action to take, and orienting drivers' attention toward trains could improve compliance.

Drivers not only have a low expectancy of trains but also have a low expectancy of encountering a grade crossing (Mortimer, 1988). In the study by Wilde, Hay, and Brites (1987) described in Section 3.1.3.3, measurements of driving speed showed high variability, suggesting that drivers only realized they were approaching a crossing only when they were close to it. This variability in approach speeds may result in rear-end crashes (Mortimer, 1988).

4.2.2 Costs of Compliance

When a train arrives at a grade crossing, drivers are usually not motivated to stop because of the potential for delay (Lerner and Ratte, 1990; Mortimer, 1988). Drivers participating in a focus group examining driver attitudes towards grade crossings indicated that they would cross the tracks in front of an approaching train if they thought there was enough time to cross safely because they viewed waiting for a train as an unwelcome delay. Even fairly minor delays perceived as being long (Global Exchange, 1994). This concern for time delays due to long warning times and false alarms may cause drivers to speed up on their approach to the crossing when the signals are not activated. This way, if the signal becomes activated, they can violate the grade crossing in the first few seconds after the signal activation, or they have enough time to violate the crossing after stopping first.

4.2.3 Risk Perception and Risk Taking

Drivers often do not perceive risk at grade crossings (Dolan, 1996; Lerner, et al., 1990). This may be the result of a misperception of potential crossing hazards (e.g., drivers are often not aware when sight distance is limited) attributable to past experiences with grade crossings. Additionally, even if risk is perceived, the driver may still choose to accept a level of risk that leads to unsafe driving behaviors (Lerner, et al., 1990). In fact, Witte and Donohue (1998) reported that approximately 10 to 20 percent of drivers are likely to exhibit risky behavior at grade crossings. In their study, 1200 Michigan residents, ranging in age from 15 to 68 years old, were surveyed to determine their perception of being involved in a grade crossing accident. Most drivers reported that they would comply with grade crossings; 80 percent of the respondents indicated that they would err on the side of caution at grade crossings, and 40 percent indicated that they would not violate a gated crossing even if there was no sign of a train. Of concern, however, was that 14 percent of drivers said they would violate a gated crossing with a train in sight, and 10 percent of drivers considered it exciting to beat the train across the tracks. Although these risk seekers understood that their risky driving behavior put them at an increased risk of a grade crossing accident, prior close calls at grade crossings also biased their judgments about their abilities to successfully beat the train again.

McKenna, Stanier, and Lewis (1991) attribute this belief to an illusion of control, in which drivers enhance their own abilities and believe they are more proficient than they really are. In fact, drivers generally believe that they are less likely to be involved in an accident than the "average" driver. Additionally, drivers may attempt to "beat the train" because they are optimistic and overconfident about their abilities to avoid a grade crossing accident. In fact, drivers are generally optimistic with regards to their skill, safe driving behavior, and accident risk relative to the average driver (DeJoy, 1989).

Several theories have attempted to explain driver behavior as a function of the level of risk the driver is willing to accept. *Risk homeostasis* models propose that drivers behave in a way to maintain an acceptable level of risk, adjusting their behavior based on their perceived subjective risk of an accident. Thus, countermeasures may not have the desired effect because drivers may "compensate" for safety improvements in traffic with less cautious driving to maintain risk at a constant level. For example, in the study by Ward and Wilde (1996), discussed in Section 3.2, drivers slowed when they approached a grade crossing with limited sight visibility because they realized that their view was restricted and were motivated to search for hazards, but when the sight obstruction was cleared, drivers increased their approach speed based on the perceived safety benefit of clearing the obstructions. *Risk-threshold* models, also called zero-risk models, propose that drivers attempt to maintain a level of zero risk. Drivers compensate when their level of perceived risk exceeds a threshold; for example, in the general driving situation, when the distance between one's car and a lead vehicle decreases (Näätänen and Summala, 1974; Summala, 1996). Finally, *risk avoidance* models propose that drivers behave to make progress towards a goal (e.g., a destination); actions selected in response to potentially aversive events are based on weighting the rewards or punishment. "Learned riskiness" results when the driver is continuously rewarded for progressively risky behavior. One example from the grade crossing situation is risk taking in response to expectations that there will be no train (Fuller, 1984, 1992).

Risk taking may also be the result of social pressure. Drivers' intentions to engage in risky behavior is not only based on their attitudes about the outcomes of that behavior but also based on their perception of social norms associated with those behaviors (Parker, et al., 1992). For example, in the survey conducted by Witte and Donohue, 30 percent of drivers indicated they would violate a gated crossing if no train was in sight if they saw another driver do so. In fact, drivers who regularly commit violations assume that their behavior is common and accepted. Manstead, et al. (1992) evaluated drivers' perception of social consensus for their actions using a questionnaire in which drivers indicated their frequency of committing driving errors and violations and their perception of how frequently other drivers committed these same errors and violations. Drivers who reported that they regularly committed errors and violations made higher estimates of the percentage of others who regularly engaged in that behavior than those who did not regularly commit errors and violations. On the other hand, drivers who did not frequently commit errors and violations tended to underestimate the occurrence of the negative behavior. Providing consensus information in campaigns to improve driving behavior may help those who routinely drive in a dangerous manner understand that their behavior is not as common as they imagine it to be.

Other studies examining drivers' motivations for violating general traffic laws find that drivers who reported that they regularly commit errors and violations showed a reduced perception of committing a violation or may simply accept a higher level of risk than other drivers. These drivers also showed less concern about how other drivers perceived their driving or the consequences of risky driving (Adams-Guppy and Guppy, 1995; Evans and Wasielewski, 1982; Palamara and Stevenson, 2003; Parker, et al., 1990; Parker, et al., 1995; Reason, et al., 1990). These same motivating factors influence the behavior of drivers who commit violations at grade crossings, so it is not surprising that Hughes, Stewart, and Rodgman (1999) found that drivers who committed traffic violations were also more likely to commit violations at grade crossings. In their study, a video ticketing system installed at one gated crossing along North Carolina's Sealed Corridor captured photographs of drivers at the crossing (the use of this system for photo enforcement will be discussed in more detail in section 5.3). The driving history of drivers who violated the grade crossing was compared to those of a general population of drivers who regularly used the crossing. The video cameras captured 64 instances of drivers violating lowered gate arms as a train approached. These drivers were classified as "violators" for the purposes of the study and were identified through photographs taken of the rear license plate of the violating vehicle and driver photographs taken of the front window of the vehicle. Hughes, et al. obtained the driving history for the two groups of drivers through the North Carolina Department of Motor Vehicles and mailed a questionnaire addressing issues related to risk perception and risk taking as related to grade crossings and general traffic situations to "violators" and the general grade crossing users. A comparison of driving history for the two groups found that "violators" were more likely to have prior speeding violations than general grade crossing users, with a non-significant trend towards a higher number of traffic violations and crashes. The questionnaire results indicated that these "violators" were more likely to find risk-taking exciting and considered trying to "beat the train" at grade crossings as less risky than the general population of drivers. The "violators" also had a limited view of the potential risk of violating grade crossings to those other than themselves.

4.2.4 Moderating Factors: Gender Differences and Age

Attitudes in driving style may be moderated by gender differences and age. As noted earlier, males are involved in more accidents than females (Elander, et al., 1993; Klein, et al., 1994; Palamara and Stevenson, 2003; Reason, et al., 1990). In their analysis of FARS data, Klein, et al. (1994) reported that male drivers were involved in 77 percent of fatal grade crossing crashes, a statistic similar to their level of involvement in fatal highway crashes. Similarly, observations of violations at actively protected grade crossings by Abraham, et al. (1998), described above in Section 3.1.3.1, showed that male drivers committed more violations than female drivers (64 percent and 36 percent, respectively) and had a higher number of violations in all five severity categories than females.

The higher violation rate for male drivers may be attributable to their greater willingness to take risks, even at grade crossings, than female drivers. An analysis of grade crossing accidents in Texas from 1992 to 1994 reported that males were involved in more accidents than females in which trying to beat the train was a primary contributing factor (Fambro, et al., 1995). Similarly, Witte and Donohue (1998) found that the "risk seekers" in their survey were more likely to be male than female. In the general highway-driving situation, males were more likely to be involved in accidents caused by intentional violation of traffic laws (e.g., the result of speeding, drunk-driving, and risky driving) than female drivers. In a study conducted by Reason, et al. (1990), drivers completed a questionnaire in which they indicated the frequency with which they committed different errors and violations while driving. Errors were considered *unintentional*, resulting from incorrect judgments or failures in information processing, whereas violations were *deliberate* deviations from safe practices, such as exceeding the speed limit or running red lights.

Driver self-reports indicated that males had more violations than females, whereas females were more prone to errors and harmless lapses during driving.

The effect of gender on accident type may be the result of differing attitudes towards driving violations. Parker, et al. (1992) found that male drivers were less concerned with the negative outcomes of committing violations than female drivers and found it more difficult to resist committing violations. In the study, participants were presented with four driving scenarios that depicted their commission of a violation: drunk-driving, speeding, close following, and dangerous overtaking. Based on the information in the scenarios, participants made judgments of their likelihood of exhibiting the behavior; the perception of that behavior by their significant others, family members, friends, law enforcement officials, other drivers on the road, and the "typical young male driver;" their evaluation of the outcome; their motivation to comply; the level of control over committing the violation; their intention; and attitude. While participants viewed all four violations as being negative, they considered speeding as being less negative than the other three types of violations. Additionally, participants' ratings indicated that they considered the negative consequences of committing the violations to have more costs than benefits. However, the data showed a trend for males to consider the outcomes of the violations as less costly than female drivers and to have weaker intentions to resist committing the violation. With respect to speeding, male drivers tended to view the risk of negative outcomes (e.g., receiving a ticket or being involved in an accident) as less likely than female drivers, considered putting the lives of others at risk through their actions as less negative than female drivers, and felt more pressure from their same-sex friends to speed than females.

The pattern of results reported for male drivers was similar to that found for young drivers. In the study conducted by Reason, et al., the rate of violations decreased with age whereas the rate of errors did not. Parker, et al. reported that young drivers were not as aware of or as concerned with the negative outcomes of driving violations as older drivers, and were more focused on the potentially positive outcomes, such as getting to a destination on time. Personal values influenced young drivers' motivation to comply with traffic laws more than external factors such as punishment. Young drivers indicated that they were more likely to commit the violations than older drivers and perceived the outcomes of committing the violations as less negative than older drivers. Additionally, young drivers perceived more approval from their peers for speeding, close following, and overtaking, than older drivers, and found it more difficult to resist committing those violations than older drivers.

In the grade crossing domain, the analysis by Klein, et al. (1994) noted that the greatest proportion of fatal accidents were attributed to drivers aged 25 to 34, but the accident rate for the 16 to 20 group (17 percent) was still fairly high, especially considering that this age group only included only a 5-year time span. While lack of experience may partially account for the high accident rate, the results of Reason, et al. (1990) and Parker, et al. (1993) show that the attitudes of young drivers must also be considered. Young drivers' aggressive driving style can be seen in the grade crossing domain. Fambro, et al. (1995) found that young drivers between the ages of 16 to 24 years old were involved in significantly more accidents where driving around the gates was a contributing factor.

Since young drivers are more susceptible to perceived peer pressure than older drivers, campaigns that stress the disapproval of their friends and significant others may be effective at changing their attitudes towards committing violations. At the same time, educational materials and programs that highlight the negative consequences of risky driving behavior and indicate that the positive outcomes are insignificant or less likely to occur than they believe may be beneficial. Finally, it is important to convince young drivers that the decision whether or not to commit a violation is something that they control (Parker, et al., 1992, 1995).

4.3 Summary

Limitations in information processing due to age, lack of experience, driver distractions, or driver impairment contribute to noncompliance at grade crossings. In general, the effects of age and experience are coupled. Younger drivers tended to have less skill and underestimated the risk of potential driving hazards (Groeger and Chapman, 1996), leading to an increased chance of being involved in an accident (Maycock, et al., 1991). With increased experience, drivers adopted a more efficient visual sampling strategy and looked at more locations than less experienced drivers (Crundall and Underwood, 1998) and were better able to detect hazards (McKenna and Crick, 1991). However, the benefits of experience decline with age. Age-related decrements in visual acuity (e.g., in contrast sensitivity) hinders the ability of older drivers to detect cues to a grade crossing, particularly at night, and read warning signs on the approach to the crossing (Staplin, et al., 1989). Additionally, older drivers tended to be less accurate than younger drivers in integrating speed and distance information to determine acceptable gap times (Clarke, Forsyth, and Wright, 1998; Clarke, Ward, and Jones, 1998) and thus were more likely to make errors estimating the speed and arrival time of the train at the grade crossing. Countermeasures to improve compliance among elderly drivers and less-experienced drivers include techniques for facilitating detection of the crossing at night (e.g., reflectorizing trackside objects) and installing additional signs at the crossing to indicate the action required (Staplin, et al., 2001).

The effects of distraction during driving and driver impairment due to alcohol use or fatigue are similar. Drivers may not realize that they are approaching a grade crossing, fail to attend to the warning device, or fail to detect a train. Much of the research addressing the effects of driver distractions or impairment has been conducted in the general highway-driving situation. Although it is acknowledged that these factors leave drivers exposed to the hazards at grade crossings, the amount of increased risk is unknown.

Drivers' failures to comply at grade crossing may also be attributable to their biases and attitudes towards compliance and their perception of the dangers at grade crossings. Drivers had low expectancies for encountering a train at a crossing (Dolan, 1996; NTSB, 1998), and some drivers did not even look for a train at a crossing (Åberg, 1988; Wigglesworth, 2001). The low expectation for trains is reinforced each time the driver passes a crossing without meeting a train at that crossing. Consequently, drivers who were familiar with the crossing were involved in more grade crossing incidents than drivers who were not (Abraham, et al., 1998).

Compliance must also be weighed with its costs; stopping for a train will result in delays, and drivers perceived even fairly minor delays to be long (Global Exchange, 1994). Unfortunately, some drivers find noncompliant behavior exciting. Witte and Donohue (1998) reported that 14 percent of drivers surveyed in their study would attempt to violate lowered gates, even with a train in sight. These "risk seekers" understood the risks of their behavior, but they were optimistic about their chances of beating the train, because of prior close calls and also possibly to overconfidence of their abilities (DeJoy, 1989; McKenna, et al., 1991). Social factors and the perceived acceptance of that behavior may also influence this risk-taking behavior (Parker, et al., 1992; Manstead, et al., 1992). For example, drivers will be more willing to violate a crossing if they see another driver do so (Witte and Donohue, 1998).

These attitudes in driving style are moderated by gender differences and age; the tendency to commit violations and the reasons for committing the violations is similar for male drivers and young drivers. Male drivers committed more violations at grade crossings than female drivers (Abraham, et al., 1998) and were involved in more grade crossing accidents than female drivers (Klein et al., 1994), particularly when attempting to beat the train was a contributing factor (Fambro, et al., 1995). Young drivers have a more aggressive driving style than older drivers and were involved in significantly more accidents due to violating gated crossings as a result (Fambro, et al., 1995). In both cases, noncompliance may be attributable to differing attitudes regarding driving violations. In the general driving situation, male drivers and young drivers were less concerned with the negative outcomes of committing violations, viewed the risk of a negative outcome as being less likely, and found it more difficult to resist committing those violations than their counterparts (Parker, et al., 1992). Countermeasures such as information campaigns to highlight the negative consequences of committing a violation and to emphasize that the driver can exert self-control to resist committing a violation may be beneficial in changing driver attitudes (Parker, et al., 1992, 1995).

5 Organizational/Management Behavior

The U.S. DOT provides funding to each state to eliminate hazards at public grade crossings through Title 23 United States Code (23 USC) Section 130 (called "Section 130 funds"), under the guidance of legislation specified in the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). Each state determines how to allocate the funds by identifying which public crossings need improvements and what improvements to make, but coordination among management and different organizations at the federal, state, and local levels is necessary for implementation. This is particularly difficult in the railroad industry where a number of different agencies are involved and various authorities exercise jurisdiction. Railroad companies own the tracks and the property on either side of the tracks (i.e., the rights-of-way). They install the tracks and are responsible for the maintenance of those tracks, the roadway between and around the rails, and the traffic control devices at the crossing. Public or private entities own the roadway at a grade crossing. Public agencies such as a municipality, county, or state agency exercise jurisdiction of and maintain public crossings. On the other hand, private parties own private crossings, which are usually located on roadways that the public does not use.

This section discusses coordination issues and collaborative efforts among federal, state, and local agencies in improving safety at grade crossings. The section addresses the coordination between federal, state, and local agencies in identifying which crossings to improve, the need for communication between railroad and highway engineers to interconnect highway traffic signals and grade crossing warning devices to prevent vehicles from being trapped on the tracks when trains approach, and the collaborative efforts between state agencies, railroad companies, and industry to improve grade crossing safety through intelligent transportation systems (ITS) technologies.

5.1 Identifying Crossings for Improvements

To assist states in determining which crossings are in need of improvement, the FRA maintains a crossing inventory and accident/incident database of public and private grade crossings that can be used in conjunction with individual state databases. However, the FRA inventory is incomplete and sometimes inaccurate because no rule mandates the reporting of grade crossing inventory information. Rather, states and railroads voluntarily submit entries into the FRA database. As a result, transit-related grade crossings maintained by the FTA are often not included in the FRA database due to incompatibilities between the two systems, and information regarding the warning devices used at grade crossings has been found to be missing or inaccurate (Bowman and Colson, 1994; Office of Inspector General, 2004).

There is also inconsistency across states for determining which crossings to improve. Whereas most states consider the train volume, traffic volume, and accident history, many do not consider physical characteristics of the crossing that contribute to safety, such as crossing angle, sight distance, curvature, or nearby intersections. Several organizations and agencies provide guidelines and standards addressing highway or railroad design to assist highway engineers for improving the safety at grade crossings (e.g., *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2004; *Guidance on Traffic Control Devices at Highway-Rail Grade Crossings*, FHWA, 2002; MUTCD, FHWA, 2003; *Railroad–Highway Grade Crossing Handbook–Revised Second Edition 2007*, FHWA, 2007). However, each state and locality still has the flexibility to develop designs for each grade crossing independently. As a result, the process for building, maintaining, and inspecting grade crossings and controlling the traffic at the crossings is inconsistent from one state to another (US DOT, 1996). In fact, the NTSB (1998) reported that the grade crossing characteristics for 54 of the 60 accidents in their study did not conform to at least one of the applicable standards and guidelines. Thus, a standardized accident prediction formula that includes all variables determined by research to be valuable in evaluating the safety of a grade crossing may be useful (NTSB, 1998).

Coordination between state and local agencies, railroad companies, highway engineers, and the public may be necessary to implement the crossing improvements. For example, the most effective countermeasure for passive grade crossings is consolidation through closure or grade separation by constructing bridges or overpasses, but proposals to consolidate or close grade crossings have met with resistance from the general public, who are concerned about its impact on emergency response times, traffic delays, the neighborhood, and convenience (Office of the Inspector General, 2004). In fact, representatives from railroad agencies have reported that only one out of 15 crossings proposed for closure actually succeeds due to public objections (NTSB, 1998).

States have taken different approaches to facilitating crossing closure or consolidation. In Missouri, a task force of representatives from county and municipal governments, state agencies, and railroad companies informed constituents of the state's reasons for consolidating or closing crossings and offered constituents the opportunity to voice their concerns (NTSB, 1998). In North Carolina, the Rail Division of the State Department of Transportation worked with municipalities to evaluate traffic patterns and establish a method for implementing improvements, while engineering consultants examined train and vehicle traffic and the economic impact of the closing. The recommendations were then presented to the public for comment (Judge, 2005). As a result of their efforts, both states have reported success in facilitating crossing closures.

5.2 Interconnection of Traffic Signals

The preemption of traffic signals at intersections near grade crossings prevents traffic queues at the intersection from extending into the grade crossing by allowing vehicles stopped on the tracks in response to at a red light at a nearby intersection, to be cleared from the tracks and prevents vehicles stopped for the train from queuing back into nearby intersections blocking the traffic flow. The failure to coordinate the timing of highway and railroad signal systems was called to the public's attention on October 25, 1995, when an Illinois commuter train collided with a school bus, stopped on the tracks, at Fox River Grove, Illinois. The bus, stopped for a red light, did not completely clear the tracks; the rear of the bus extended about three feet into the commuter train's path. The NTSB determined that while the probable cause of the accident was the fact that the bus driver had stopped the school bus on the railroad tracks, the failure by the state to take sufficient action to prevent vehicles from stopping on the railroad tracks at that intersection was a contributing factor (NTSB, 1996). In fact, tests conducted by the NTSB after the accident, showed that that while the active warning devices at the crossing provided the required minimum 20 second warning time before the approach of a train (FHWA, 2003), in approximately 50 percent of the trials, the traffic lights provided 10 seconds or less clearance time for vehicles at the highway intersection to clear the tracks.

Signal preemption requires coordination by the railroad companies, local and state transportation departments, light rail transit agencies, and regulatory authorities. In particular, both highway and railroad agencies must work together to ensure the appropriate timing of signals. Poor communication between these modal agencies has led to problems integrating highway and rail traffic control devices, such as adequate information regarding traffic flow (Caird, et al., 2002).

Preemption of traffic signals near grade crossings is complex and the design of the warning systems must be customized for each specific location to take into account the unique conditions. To ensure that there is sufficient time for vehicles to vacate the track when a train is approaching, calculations of maximum preemption time considers three parameters:

(1) the time needed following the start of the preemption sequence for traffic signals to complete the transfer of the right-of-way to the grade crossing warning signal,

(2) the time for vehicles stopped within the minimum track clearance distance to move through the crossing, and

(3) the time the minimum track clearance distance must be clear of vehicles prior to the train's arrival.

Simultaneous preemption, in which the highway traffic signal and railroad active warning devices are notified at the same time of an approaching train, may be used when maximum preemption time is equal or less than the minimum warning time. If the maximum preemption is greater than the warning time, then advance preemption, in which the traffic signal provides notification of an approaching train before the grade crossing warning device, may be necessary. Once signal preemption is implemented, ensuring continued compliance of the interconnected system may require joint inspections by the appropriate rail and highway authorities. For example, rail inspectors may consider grade crossing warning signals to perform effectively without considering the highway traffic demands. Conversely, highway engineers may consider highway traffic signals to perform adequately without considering rail operations (Bremer and Ward, 1997; FHWA, 2002; U.S. DOT, 1996).

Preemption practices vary widely. The MUTCD recommends that signal preemption be considered when the distance between the grade crossing and a signalized intersection is less than 200 ft (60 m) (FHWA, 2003). The *Railroad-Highway Grade Crossing Handbook–Revised Second Edition* (FHWA, 2007) recommends signal preemption at grade crossings near highway intersections that lead to either of the following two conditions (FHWA, 2007):

- The potential for highway traffic queues to extend across a nearby rail crossing; or
- The potential that traffic queue from a nearby downstream grade crossing could interfere with the signalized highway intersection.

Additional guidance on signal preemption is provided in the *Preemption of Traffic Signals NearRailroad Crossings: An ITE Recommended Practice* (ITE, 2006).

Different states have taken different approaches to preemption and coordination. Michigan and South Carolina reported success with pre-signals; these are traffic signals upstream of the standard highway traffic signals controlling the intersection. In Michigan, the use of pre-signals made additional pre-emption unnecessary, and in South Carolina, enforcement of pre-signals actually encouraged drivers not to stop their vehicle on the tracks, regardless of whether a train was approaching or not. Oregon and Wisconsin implemented methods to coordinate the appropriate parties. In Oregon, public authorities responsible for maintaining an interconnected signal system must notify the railroad dispatcher so that train crews operating through grade crossings with malfunctioning traffic signal preemptions systems are aware of the problem. In Wisconsin, notices are placed in the traffic signal controller and railroad equipment cabinets to alert engineers that the device is part of an interconnected highway-rail signal system and that any modifications to either system require coordination with the appropriate parties (Korve, 1999).

5.3 Intelligent Transportation Systems (ITS)

State agencies, railroad companies, and industry have collaborated to develop, introduce, and evaluate ITS applications to improve grade crossing safety. New digital data communications, computer, and sensor technologies installed along highways and transit systems are expected to improve safety, efficiency, productivity, control, and communication. Examples of ITS applications at grade crossings include the implementation of second train warning signs at grade crossings (discussed in Section 3.1.1.3), in-vehicle warning systems and variable message signs located along the highway to alert drivers of approaching trains (discussed in Section 5.3.1), advanced warning of railroad delays (discussed in Section 5.3.2), and the use of automated photo enforcement (discussed in Section 6.3). In the long term, ITS technology is expected to facilitate the development of “intelligent grade crossings” where ITS for railroads and vehicles are integrated. This will be discussed in more detail below in Section 5.3.3.

While several states have initiated ITS programs that address similar functions, different, and often competing, technologies are used. A general overview of ITS systems and summaries of ongoing ITS efforts can be found in Carroll and Oxley (1999) and Gribbon (1997).

5.3.1 In-Vehicle Warning Displays

One application of ITS technologies is to assist drivers in detecting the presence of a grade crossing or train through the presentation of in-vehicle alerts. These systems will be particularly useful at crossings where there is limited sight distance to the crossing, along the track when approaching the crossing or when stopped at the crossing (Caird, et al., 2002). The Minnesota Department of Transportation in conjunction with 3M Corporation, Dynamic Vehicle Safety System, and Hughes Transportation Management System developed the use of an in-vehicle signing system that detected the presence of grade crossings and approaching trains and broadcasted that information to drivers (SRF Consulting Group, 1998). The displays were installed in 29 school buses in Minnesota for evaluation during the 1997–1998 school year. Sensors, installed at five active grade crossings, transmitted signals to a receiver located at the grade crossing, which in turn communicated with the in-vehicle unit to present auditory and visual alerts when the bus was in close proximity of a grade crossing and indicated whether a train was at or near the crossing. To increase credibility of the warning, sensors at four of the five of the crossings possessed a directional feature that allowed the system to determine the direction of the bus relative to the crossing and inhibited warnings if the bus was in vicinity of the crossing but did not intend to cross the tracks. Because the fifth crossing was located at a complex geometric approach, the accuracy of the directional feature was limited, so the feature was not used. In the evaluation study, driver behavior at the crossings equipped with the warning system was observed and compared to behavior at similar grade crossings without the warning system. Objective data consisted of the bus’ approach speed and stopping distance and the bus driver’s scanning behavior. Additionally, bus drivers provided subjective data regarding the accuracy, usability, utility, and effectiveness of the system.

The objective measures showed no differences in driver behavior at grade crossings equipped with the warning system to those without the system. Interestingly, the observations showed that bus drivers' compliance with state laws regarding the actions required at grade crossing rules was not ideal. Although bus drivers must come to a full stop at grade crossings, activate their flashers, and look both ways at the crossing, some did not stop at all. The subjective measures showed that bus drivers generally perceived the system to be effective in alerting them to the presence of a grade crossing and to the presence of a train. However, drivers' confidence in the warning system and their perception of its accuracy was higher at crossings where the directional feature was available. The rate of false notifications at the crossing without the directional feature reduced driver confidence in the system.

A subsequent study evaluated the use of the in-vehicle alerting display at passive grade crossings. Only subjective data was collected in this evaluation. Bus drivers, interviewed regarding their perceptions, indicated that they felt that the system improved safety. While the results are promising, additional tests are necessary due to the small number of observations.

The Illinois Department of Transportation developed a similar system in conjunction with Raytheon Company, Metro Transportation Group, and Calspan SRL. In the system, a trackside transmitter signaled in-vehicle receivers (IVR) when trains were approaching or occupying a grade crossing (Benekohal, 2004; Benekohal and Aycin, 2002, 2004; Benekohal and Rawls, 2004a, 2004b). To demonstrate the system, transmitters were installed at five active grade crossings, used by passenger, freight, and commuter trains, in the northern Chicago suburbs, and 300 in-vehicle displays were installed in the vehicles of 38 participating public and private organizations. The in-vehicle display presented alerts in one of three modes: visual, auditory, or visual plus auditory. Two groups of drivers participated in the study. One group experienced all three alerting modes of the IVR system, each for a 3-month period, and the other used the IVR system in the visual mode only for 9 months. For the former group, their perception of the system was evaluated through questionnaires at four times throughout the study: once prior to using the system, and then 3, 6, and 9 months after using the system. For the latter group, their perception was evaluated twice; once before using the system and then again 9 months later. Feedback was also obtained through three focus groups: one with some of the drivers, a second with operations managers who reported feedback from their drivers, and a third with members of the project team who used the IVR system in their vehicles.

Driver opinions regarding the effectiveness of the IVR system were mixed. The questionnaire results indicated that over the 9-month period, less than half the drivers rated the effectiveness of the IVR system as "high" or "very high" (an average of 43 percent with 40 percent of drivers rating it as "high" or "very high" after three months, 46 percent after 6 months, and 42 percent after nine months). In fact, an average of 25 percent of drivers rated its effectiveness as being "low" or "very low" (25 percent after three months, 24 percent after six months, and 27 percent after nine months). Not surprisingly, the perceived effectiveness of the IVR system was influenced by false alerts. As a result, only an average of 15 percent of drivers indicated that they trusted the system very much (14 percent, 18 percent, and 13 percent of drivers after 3, 6, and 9 months, respectively), and a greater number of drivers (an average of 38 percent) indicated that they did not trust the system at all (36 percent, 34 percent, and 43 percent after 3, 6, and 9 months, respectively).

In general, participants in the study did not perceive the IVR system as being as effective as current active warning devices used at the grade crossing or the warning provided by the train horn. When drivers rated the effectiveness of the IVR system and that of warning devices at grade crossings (gates, flashing lights, bell, train horn, advance warning sign, and crossbuck sign), the ratings showed that drivers considered gates and flashing lights to be most effective followed by the bell and the train horn. The IVR system and advance warning and crossbuck signs were considered to be the least effective. However, the mode in which the IVR system presented the alerts influenced drivers' effectiveness ratings; when participants used the IVR system with auditory alerts (either alone or in conjunction with visual alerts), they rated the system as being comparable to that of other auditory warnings at the crossing (i.e., the bell and train horn). The effectiveness ratings suggest that drivers relied on other sources of information to determine whether there was a train at the crossing. In fact, focus group results indicated that drivers did not understand why an IVR system was needed at crossings protected by flashing lights and gates. Only 47 percent of drivers felt the system should be installed at more grade crossings, and the number of drivers who indicated they would continue using the system (47 percent) was almost equal to the number who indicated that they would not (42 percent).

The results from the evaluations in the states of Minnesota and Illinois highlight the fact that drivers' perceived reliability of the system's effectiveness is an important factor in compliance. This is similar to drivers' responses to active warning devices, discussed in Section 3.1.3.3. Chugh and Caird (1999) conducted a study to further examine the effect of reliability on driver compliance with an in-vehicle warning display. Participants were shown driving scenes of grade crossings in a driving simulator and were asked to slow and stop as they approached the grade crossing. At some crossings, participants received visual and auditory warnings about approaching trains via an in-vehicle head-up display. The reliability of the warning signal was varied at two levels (83 percent or 50 percent). The experiment consisted of four blocks of trials. In the first two blocks, the warning system was 100 percent reliable. In the third block, the reliability was reduced, and participants experienced one of the three failures: a false alarm in which the system presented a warning when no train was present, a false alarm in which the system presented a warning with no crossing, or a missed signal in which the system failed to alert the driver to a train. In the fourth block, the reliability of the warning system returned to 100 percent. "Baseline" data on driver response times to grade crossings was collected in the first two blocks of trials and compared to driver reaction times to the failures in the third block of trials. As expected, the results showed that false alarms and missed signals affected driver behavior differently. Drivers responded slower to warnings after false alarms were presented. In fact, when the warning system was only 50 percent reliable, 6.9 percent of participants no longer responded to the warning system after experiencing false alarms. On the other hand, participants responded faster to grade crossing warnings after a missed signal. Response time returned to baseline levels in the fourth block of trials only when reliability was high (83 percent). Although trust in the warning system was not sensitive to the failure type (i.e., false alarms versus missed signals), trust decreased due to the system reliability, and did so to a greater degree when the reliability level was 50 percent than when it was 83 percent. However, in both cases, participants regained their trust in the warning system by the end of the fourth block of trials. Of particular concern is the possibility that the use of such a system may induce over-reliance, such that drivers no longer search adequately at crossings for approaching trains or other hazards (Caird, et al., 2002).

5.3.2 Advanced Warning of Railroad Delays

The Texas Department of Transportation proposed the development of a system to alert drivers of delays at grade crossings due to the presence of a train or other obstruction. In the proposal, sensors, placed along the railroad tracks, would detect the presence, speed, and length of approaching trains and transmit that information to a control unit that calculated the time and duration those grade crossings at or near highway exits would be blocked. The information would then be broadcasted to in-vehicle displays in public vehicles and presented on variable message signs along freeways. The original proposal also called for the installation of sensors and cameras at grade crossings to detect the presence of vehicles on the tracks. If a vehicle was detected, the system would transmit a warning and image of the crossing to oncoming trains. However, the railroads were concerned that the implementation of such a system would transfer liability from the vehicle to the rail company and were hesitant to participate in the study. As a result, the project was modified to focus on driver information, and participation of the railroads was not mandatory. The prototype Advanced Warning to Avoid Railroad Delays (AWARD) used sensors, mounted on poles that did not intrude upon the railroad companies' right-of-way, to collect information on a train's arrival time at a grade crossing and the duration of the train. The sensors relayed information to variable message signs, located along the freeway, so that drivers could select alternative routes. The first test of the system occurred in San Antonio and consisted of field interviews and the development of simulation models that measured whether a reduction in delays on freeways and access roads near the grade crossing resulted.

Unfortunately, the results of the study indicated no actual need for the AWARD system at the location selected. Field interviews indicated that the presence of a train at the selected location rarely caused traffic to back onto the freeway, since the crossing selected had low train volume (only 2 to 3 trains per day) and trains generally crossed at off-peak times. The simulation results confirmed the results of the driver interview, showing that the presence of trains at the selected crossing rarely disrupted freeway operations. In fact, the results of the simulation predicted that drivers would benefit more from simply waiting for the train to pass than selecting an alternate route. In the study, in-vehicle navigation units carried by emergency service providers also displayed AWARD information on train delays, but driver interviews indicated that this feature was not used frequently due to a lack of knowledge of the feature and problems with the displays.

While the implementation of the AWARD system was not warranted at the crossings in the study, the demonstration was successful. It is hypothesized that the system may have future benefits with growth in train and traffic volume. The city of Houston is considering similar efforts to integrate train location and speed into traffic management systems as part of their ITS Priority Corridor Project (Carter, 2001).

5.3.3 Intelligent Grade Crossings

It is worth noting that the long-term vision for ITS technology is the development of "intelligent grade crossings" where intelligent rail technology is integrated with intelligent automotive technology. One vision consists of rail operations centers that have real-time information regarding the location, direction, and speed of each train, communicating with automotive ITS service providers, who have real-time information regarding the location, route, and speed of each vehicle. Rail operations centers could notify ITS service providers of the approach of trains at grade crossings, and this information could be passed along to alert drivers approaching a grade crossing as to whether or not a train is present. At the same time, ITS service providers could communicate with rail operation centers and notify them if a vehicle becomes disabled at a grade crossing so that trains could be slowed or stopped to prevent a collision (Weiland and Woll, 2002).

The New York State Department of Transportation is collaborating with Alstom, Inc. to develop the Intermodal Control System (ICS) for the Long Island Rail Road. The ICS integrates the control of trains, warning devices at grade crossings, and traffic through three components: *automatic train control*, an *intelligent grade crossing controller*, and an *intelligent traffic system*. The *automatic train control* determines train position and speed based on information received from transponders mounted on the tracks and readers mounted in the trains. Positive train separation can be achieved by limiting train speed based on the length of clear track ahead, the train's speed, and its acceleration and deceleration profile. The *intelligent grade crossing controller* operates the active warning devices at the crossing and communicates with the *intelligent traffic system* that presents information regarding approaching trains and gate operations to in-vehicle displays or variable message signs. Additionally, the intelligent traffic system can receive requests from emergency vehicles approaching the crossing if signal preemption is needed, and interfaces with the intelligent grade crossing controller and automatic train control to determine whether the request can be accommodated.

The impact of the ICS is expected to reduce delays at the crossing by facilitating the presentation of a constant warning time at the crossing, preventing gates from being lowered if the train has stopped upstream of the crossing, and controlling the timing of traffic signals near the crossing to minimize the delay resulting from the gate down time. A cost-benefit analysis based on seven prototype scenarios that varied in the level of train traffic, vehicle traffic, and whether the train was continuing through the crossing or stopping at the crossing indicated that the system, implemented at a cost of $150,000, had approximate net benefits in savings of $225,000 in preventing vehicle delays and $307,000 in reducing collisions (Carroll and Oxley, 1999; Lee, et al., 2004; Gribbon, 1997).

5.4 Summary

Coordination among federal and state agencies, local municipalities, railroad companies, and industry is needed to improve the safety of grade crossings. The FRA maintains a crossing inventory and accident/incident database of public and private grade crossings that can be used to assist states in determining which crossings to improve, but states and railroads must voluntarily submit information to keep this database accurate and up-to-date (Bowman and Colson, 1994; Office of Inspector General, 2004). Additionally, implementation of countermeasures may require coordination with the public and the appropriate highway authorities (NTSB, 1998; Judge, 2005). In particular, the use of signal preemption, requires that highway and rail agencies work together to ensure the appropriate timing to signals to allow vehicles to vacate the track when a train is approaching and also to ensure continued compliance of the interconnected signals (Bremer and Ward, 1997; US DOT, 1996).

States have taken different approaches to improving grade crossing safety. States use different formulas to determine which crossings to improve (Bowman and Colson, 1994) and different processes for building, maintaining, and inspecting grade crossings (U.S. DOT, 1996). Several states have pursued efforts to develop and implement ITS technologies to alert drivers to the presence of a grade crossing or train. The states of Minnesota and Illinois examined the use of in-vehicle display to alert drivers to the presence of grade crossings and approaching trains (Benekohal, 2004; Benekohal and Aycin, 2002, 2004; Benekohal and Rawls, 2004a, 2004b; SRF Consulting Group, 1998); the state of Texas evaluated the use of variable message signs, located along freeways, to inform drivers of the approach of a train at grade crossings near freeway exists so drivers could select alternate routes (Carter, 2001); and the state of New York developed a plan to implement an intelligent grade crossing system where technologies for trains, grade crossings, and traffic control are integrated (Carroll and Oxley, 1999; Lee, et al., 2004, Gribbon, 1997). The impact of these systems depended not only on the reliability of the system but also drivers' perceived reliability of the system. Drivers did not trust systems that had a high rate of false alarms; consequently, these systems were underutilized (Benekohal, 2004; Benekohal and Aycin, 2002, 2004; Benekohal and Rawls, 2004a, 2004b; Chugh and Caird, 1999; SRF Consulting Group, 1998).

6 Environmental Factors

The outermost layer of the sociotechnical system addresses the political, social, and cultural forces that affect safety at grade crossings. The failure to recognize these forces can prevent the implementation of valid safety improvements or result in an implementation that is ineffective. The FRA guides the direction of its safety program on accident and inspection data to address those areas with the highest safety risks through regulations and countermeasures to improve compliance. This section considers the policies and actions of regulators and the effects of education and enforcement. First, the role of the public in the development of regulations is discussed in the context of the FRA's efforts to develop regulation requiring the use of train horns. Second, methods for educating the public and the effectiveness of these programs are addressed. Finally, approaches to enforcement, and in particular the concerns in the implementation of photo enforcement at grade crossings, and its effectiveness are discussed.

6.1 Regulations: Repealing the Whistle Ban

The implementation of FRA regulations requires significant interaction between local communities and municipalities, state agencies, and railroads to balance safety concerns with community quality of life issues. An example of the value of this interaction was demonstrated in the FRA's process to develop a policy regarding the use of train horns at grade crossings. The train horn has long been accepted as one way to indicate a train's proximity to the grade crossing, and state laws and railroad companies mandated its use (FRA, 1995b). As discussed in Section 3.3.3, residents living in communities near railroad tracks noted the adverse impact of train horns on their quality of life. In the 1970s, special interest groups looked for ways to silence train horns and lobbied states and local counties throughout the nation to establish local whistle bans prohibiting the sounding of the horn as the train passed through the community, despite safety concerns from the railroad industry.

Whistle bans were especially widespread along Florida's east coast rail line, where in 1984, local governments enacted a nighttime whistle ban that prevented trains from sounding their horn between 10 p.m. and 6 a.m. The whistle bans applied only to grade crossings owned by the Florida East Coast Railway Company (FEC). In 1990, the FRA conducted a study to examine the effect of the Florida whistle ban to determine if there was any correlation between communities with regulations against sounding the train horn and their nighttime accident rate (FRA, 1995a). An analysis compared the accident rate for 600 of FEC's grade crossings, 85 percent of which were affected by the whistle ban, to four data sets:

1) the number of nighttime accidents at those crossings before the enactment of the whistle ban,
2) the daytime accident rate at those crossings (i.e., when sounding the train horn was allowed),
3) the accident rate at crossings unaffected by the whistle ban, and
4) the accident rate for similarly equipped crossings owned by a different rail company (CSX Transportation, Incorporated (CSX)) unaffected by the whistle ban. The analysis included accident data from 1975 through 1989.

The results showed that whistle bans had a significantly negative impact on safety. FEC's nighttime accident rate at whistle-banned crossings increased by almost three times after the enactment of the whistle ban (39 accidents before the ban versus 115 accidents after the ban), with no change in their daytime accident rate. In contrast, the nighttime accident rate at FEC's crossings, unaffected by the whistle ban increased by only 23 percent. A comparison of FEC's accident rate with that of CSX, who did not need to comply with the whistle ban, showed that although nighttime accident rates increased at both railroads, CSX's accident rate increased by 67 percent whereas FEC's accident rate almost doubled.

Further examination of the data highlighted the safety impact of the Florida whistle ban. When accidents that would not have been prevented by the train horn were eliminated from the analysis (e.g., accidents caused by vehicles stopped or stalled on the tracks), the accident rate increased by 467 percent (21 accidents before the ban versus 98 after the ban). Additionally, examination of vehicle-train collisions indicated that before the enactment of the whistle ban, accidents in which the driver struck the train occurred long after the locomotive sounding the horn had passed through the crossing (on average, vehicles hit the 37th train car behind the locomotive) whereas after the whistle ban, vehicles hit the 12th car behind the locomotive. Based on the results of this analysis, the FRA issued Emergency Order No. 15, which required FEC to sound their train horns at all public grade crossings. An examination of the accident rate 2 years after the issue of the emergency order showed that the nighttime accident rate fell by 69 percent, returning to pre-whistle ban levels (FRA, 1995b; 2005a).

In 1991, the FRA issued a notice announcing their intention to issue a nationwide rule regarding the use of train whistles at grade crossings. As part of this rulemaking initiative, the FRA conducted a nationwide study of train whistle bans in conjunction with the Association of American Railroads (AAR) to determine how many crossings in the nation were subject to whistle bans and whether the nationwide data showed an increased accident risk at whistle-ban crossings, similar to that found in Florida (FRA, 1995b). AAR surveyed railroad companies and asked them to provide a list of all their crossings subject to whistle bans. Twenty-five railroad companies responded to the survey, 17 of which operated along grade crossings subject to whistle bans. AAR reported whistle bans at 2,122 grade crossings across 27 states, with 94 percent of the whistle bans in effect 24 hours of the day. Note that the 537 Florida grade crossings subjects to whistle bans were not included in the count nor were they included in the nationwide study.

To determine if there was an increased safety risk as a result of whistle bans, the change in the accident rate before and after the enactment of the whistle bans was examined using accident data from 1989 through 1993. The nationwide accident analysis showed results similar to that found in the Florida study (FRA, 1995a); crossings with whistle bans had on average 84 percent more collisions than similar crossings with no whistle bans. The cancellation of whistle bans at some of these crossings allowed a direct comparison of the accident rate during and after the ban, and showed an average of 38 percent fewer collisions in the post-ban period. An "Accident Prediction Formula" that calculated the likelihood of an accident at a grade crossing based on its physical characteristics (e.g., the number of tracks and highway lanes, types of warning devices, rural or urban location, road condition) and operational aspects (e.g., number of highway vehicles and train volume, speed, type, and schedule) found that the risk of a grade crossing accident was 84 percent higher when the train horn was silenced (FRA, 1995b).

The FRA began an outreach program to share their findings with communities with whistle bans and to better understand local issues and concerns. During this outreach, an additional 664 crossings subject to whistle bans that had not been included in the 1995 study were identified, with 95 percent of these crossings located in Chicago, Illinois. As a result, the FRA conducted a second nationwide analysis that included these additional crossings and used updated accident data from 1992 to 1996. The FRA also refined their methodology for the accident analysis by examining the effect of the whistle ban as a function of the protection level at the crossing (i.e., signs only, flashing lights only, or flashing lights and gates) and by excluding from their analysis those accidents where sounding the train horn would not have been a factor (e.g., accidents involving pedestrians or accidents where the vehicle hit the side of the train beyond the fourth train car). As in the previous nationwide study (FRA, 1995b), the analysis excluded the data from the state of Florida. Consistent with the results of the previous study, the analysis showed that the whistle ban impacted safety, with a 62 percent increase in accidents at whistle-ban crossings protected with gates, 119 percent increase at whistle-ban crossings protected by flashing-lights only or another type of active warning device, and a 27 percent increase at whistle-ban passive crossings. Of note was the fact that an accident resulting because a motorist drove around lowered gates was 128 percent higher at whistle-ban crossings than at non-whistle ban crossings (FRA, 2000).

Interestingly, FRA (2000) analysis noted one anomaly: crossings with whistle bans in the Chicago Region of northeastern Illinois did not have an increase in their accident rate. In fact, the accident rate at crossings with whistle bans was 16 percent lower than the accident rate at crossings without whistle bans. An examination of the ten-year accident rate at grade crossings in Illinois between 1988 and 1998 showed 48 percent of all grade crossing accidents occurred at crossings with whistle bans and 52 percent at crossings without the whistle ban. A calculation of the accident likelihood based on the number of grade crossings and the accident rate over the past 10 years showed only a slightly higher risk of an accident at whistle ban crossings (7.1 percent versus 5.1 percent for non-whistle ban crossings) even though crossings with whistle bans experienced significantly higher train and traffic volumes (Laffey, 2000).

On January 13, 2000, the FRA published a Notice of Proposed Rulemaking (NPRM) addressing the use of the locomotive horns at grade crossings, solicited written comments from the public for approximately 5 months, and held public hearings. As part of this comment process, various states informed the FRA that they had more accurate data and information regarding which crossings were subject to whistle bans, and the amount of this data was sufficient to warrant an update to the FRA (2000) nationwide study. Additionally, commenters from the Chicago Region presented the FRA with the results of their regional analysis, and commenters from Wisconsin noted that although there were a significant number of crossings in the state with whistle bans but without active warning devices, the crossings had good safety records.

Based on the feedback received, the FRA contracted Westat, Inc., to update the FRA (2000) data analysis with the new data and to specifically evaluate the regional effects of whistle bans in the Chicago Region and the state of Wisconsin. Westat, Inc. conducted two analyses. In the first, updated data (again excluding data from Florida) for the same time period examined in the FRA (2000) study (i.e., 1992 to 1996) was re-analyzed, with similar results; whistle bans had a negative impact on safety on a nationwide basis. Again, the data for the Chicago Region showed a higher accident rate at non-whistle ban crossings than at whistle ban crossings. When the accident rate for whistle ban crossings in the Chicago Region was compared to the nationwide data for similar crossings where trains sounded their horns, the results showed no difference in accident rates at passive crossings and crossings protected only by flashing lights. However, the results showed a significantly higher accident rate at gated crossings in the Chicago Region subject to whistle bans compared to similar non-whistle-ban crossings nationwide. The FRA believed that this finding suggested that observation of the whistle ban was discretionary, and that locomotive engineers did not sound the horn at crossings that they considered inherently safer than other crossings. In fact, the FRA had received information suggesting that several hundred crossings believed to be under a whistle ban were not or had not been for several years. With regards to the state of Wisconsin, due to a small sample size, no difference was found between the accident rates at whistle ban versus non-whistle ban crossings (*Use of Locomotive Horns at Highway-Rail Grade Crossings; Interim Final Rule*).

In the second analysis, Westat, Inc. updated the nationwide data and compared the accident rates from 1997 through 2001 at whistle-ban crossings versus non-whistle ban crossings (again excluding data from Florida). Additionally, the data for the Chicago Region was updated to reflect more accurately the number of non-whistle banned crossings. Similar to the previous analyses, the results showed a higher nationwide accident rate at whistle ban crossings than at non-whistle ban crossings. The results reported a 43 percent difference in accident rate at gated crossings, a 22 percent increase at flashing-light only crossings, and a 72 percent increase at passive crossings. With respect to the Chicago Region, once again, the data showed no statistical difference in accident rates, but suggested that accidents at gated crossings without a whistle ban had a 17.3 percent higher risk of a grade crossing accident than non-whistle ban gated crossings in the nation (Zador and Duncan, 2003). However, results of independent studies conducted in Illinois noted that this 17.3 percent increased risk was not statistically significant and therefore these studies concluded that there was no overall difference in safety (*Use of Locomotive Horns at Highway-Rail Grade Crossings; Final Rule*).

The FRA Final Rule on the use of train horns is codified in 49 CFR § 222 and 229. The regulation requires the sounding of the train horn, except at crossings where there is no significant risk of loss of life or injury, where other safety measures are in place to compensate for the absence of the warning provided by the train horn, or where use of the train horn is not practical. The Final Rule preempts all local whistle bans at public grade crossings, with an exception for crossings in the Chicago Region, in which current whistle bans can remain in effect pending further data analysis. For all other regions, the rule allows local traffic control and law enforcement authorities to establish Quiet Zones, sections of a rail line with one or more consecutive public grade crossings where train horns are not sounded. Coordination with railroad companies is required to establish these Quiet Zones since supplemental safety measures, such as active warning devices, will need to be in place to mitigate the silencing of the train horn (*Use of Locomotive Horns at Highway-Rail Grade Crossings; Final Rule*).

6.2 Education

Public education can inform drivers of the dangers at grade crossings and of the actions required. Rules specifying driver actions at grade crossings vary from state to state, and some states do not even discuss grade crossings in their driver education manuals (Jeng, 2005). One popular education program, Operation Lifesaver, was first established in 1972 in Idaho to increase awareness of safety issues at grade crossings and encourage safe driving behavior. Since then, each state has adopted the program, although the programs operate independently. Operation Lifesaver is a volunteer organization with participation from railroads, law enforcement, and communities. Its primary activity consists of presentations at schools, drivers' education classes, and communities. Federal, state, and local government agencies, railroads, and highway safety organizations sponsor programs.

Nationwide, Operation Lifesaver has had a positive safety impact. The results of the negative binomial regression accident analysis conducted by Mok and Savage (2005), discussed earlier in Section 3.3.1, found that Operation Lifesaver reduced the number of vehicle-train collisions by 15 percent and the number of deaths by 19 percent. According to the analysis, the effectiveness of Operation Lifesaver in reducing grade crossing fatalities was greater than that prevented by the installation of active warning devices at passive grade crossings. Additionally, the authors noted a period of swift decline in the accident rate from 1979 to 1983 that coincided with the time when states across the country adopted the Operation Lifesaver program. In that five-year period, the predicted accident rate dropped by almost 40 percent, and Operation Lifesaver prevented 1,455 incidents and 164 fatalities annually. Since the early 1980s, grade crossing safety has improved significantly, attributable not only to Operation Lifesaver but also to the implementation of other countermeasures. As a result, the impact of Operation Lifesaver, while still positive, has been reduced, although the program is still credited with preventing 500 incidents and 75 fatalities annually.

It is important to mention one note of caution in interpreting the results of the regression analysis. As indicated earlier, the analysis conducted by Mok and Savage did not include a comprehensive list of factors that contribute to grade crossing violations. Consequently, the factors included in the analysis may appear to have a greater impact than is actually the case. While it is clear that Operation Lifesaver has had a positive safety impact, it is important to note that the estimates of its relative contribution may not be as great as the regression analysis indicated.

Because the Operation Lifesaver program is implemented differently in each state, it is valuable to measure the relationship between the extent of activity in a state and the difference in activity level from year-to-year to determine their effect on reducing the accident rate at grade crossings. This was the goal of a second negative binomial regression analysis, conducted by Savage (2006), using accident data from 1996 through 2002. The results of the analysis showed a significant positive effect of Operation Lifesaver activity in reducing the number of incidents; increasing the activity level was shown to reduce the number of collisions with a point elasticity of –0.11. Since most drivers are often unaware of the risks at grade crossings and unsure regarding the action required, the result of the regression analysis showing a benefit to public education is not surprising, but does highlight the safety benefits of making drivers better informed. However, the result did not speak to the effectiveness of any one program and what educational cues were most beneficial.

Several studies have evaluated the effectiveness of Operation Lifesaver activities within a state. The General Accounting Office (GAO) reviewed active education and enforcement programs and noted the success of the Ohio Operation Lifesaver program in reducing grade crossing accidents in that state by 75 percent in the 25 years from 1978 to 1993 (US GAO, 1995). Ohio's program used three methods to target different segments of the population and alert current and future drivers to the consequences of violating grade crossings: Officer-on-the Train, Trucker-on-the-Train, and mock train crashes. In the *Officer-on-the-Train* approach, law enforcement officials and media rode in a train cab and observed driver behavior at grade crossings. When law enforcement officials observed driving violations, they radioed vehicle descriptions to state and local police at the crossing, who then cited the drivers for the violation. The *Trucker-on-the-Train* approach was similar to the *Officer-on-the-Train* approach with commercial vehicle operators in the train cab rather than law enforcement officials. Finally, *mock train crashes* were demonstrated to school-aged children to highlight the severity of vehicle-train accidents.

In Iowa, the implementation of one Operation Lifesaver program had a short-term positive effect on driver behavior. A safety campaign lasting for one-month consisted of presentations in schools, with special emphasis on high schools and driver education courses; a 3-day open house at a railway depot; an accident investigation course for law enforcement; and public media assistance to increase awareness through billboards, newspaper articles, video billboards on local cable channels, mayoral proclamation declaring April 1991 as Operation Lifesaver month, information booths at shopping malls, and safety messages at fast food restaurants and grocery stores. The effectiveness of the campaign was measured by collecting data on drivers' approach speed to the crossing, vehicle speed when crossing the tracks, looking behavior, and braking behavior at 22 grade crossings two months prior to a 1-month long Operation Lifesaver campaign and again 1 month after the campaign.

The results after 1 month showed that the campaign succeeded in reducing vehicle approach speeds and crossing speeds but did not alter drivers' looking behavior or increase their likelihood of stopping at the crossing (Brewer, 1992). However, the positive speed reduction benefits did not last in the long-term. A follow-up study, conducted 6 months after the campaign, showed that approach speeds and crossing speeds had returned to levels recorded before the campaign. The results suggest that a one-time public education campaign was not sufficient to improve driver behavior in the long term but rather highlighted the need for continuous education (Iowa Department of Transportation, 1992). The results are consistent with research on warnings showing that the effectiveness of warnings decreased the farther away they were presented from the hazard in terms of time or space (Kalsher and Williams, 2006; McCarthey, Ayers, and Wood, 1995).

Although educating the public about grade crossing hazards may dissuade some drivers from violating crossings, the design of safety campaigns should also consider the social aspects of driving behavior and in particular, methods for changing drivers' motivation and attitudes rather than their skill and knowledge. Since drivers believe they are more skilled than they really are, safety campaigns may not succeed because drivers may feel the message is directed to others who are less skilled (McKenna and Lewis, 1991). Additionally, young drivers, who perceive more approval from their peers than older drivers to commit violations, as noted in Section 4.2.4, may respond more to campaigns that highlight disapproval from peers for risky behavior and emphasize drivers' self-control over committing violations than to educational campaigns (Parker, et al., 1992, 1995). Safety campaigns may also take advantage of drivers' tendency to imitate other drivers. Although this tendency is often observed in the commitment of violations (e.g., a driver violates a grade crossing because the lead vehicle did so without consequences), this same tendency may improve compliance if desirable driving behavior is highlighted (Wilde, et al., 1971).

Educational campaigns may also be implemented in conjunction with enforcement. FRA and the Illinois Commerce Commission examined the effectiveness of education combined with enforcement in improving safety in a joint program (Illinois Commerce Commission, 2005; Secretary of Transportation, 2004). Representatives from the two organizations met with representatives from local railroad companies and Illinois communities to review rail safety concerns and develop a customized safety program to meet the needs of each community.

Although the specifics of the programs varied from one community to another, the education and enforcement programs consisted of the following core components:

Education

- Programs aired on cable access channels and local radio, which consisted of 30-second public service announcements and in-depth 5-, 10-, and 30-minute safety segments,
- Videos, played on a continuous loop, at points of interest around town (e.g., commuter rail stations, shopping centers, and schools),
- Contests in local schools to develop safety posters,
- “It’s the Law” safety poster campaign in which posters were placed in the windows of stores near commuter rail stations,
- Rail safety messages played on community telephone systems to callers on hold,
- Use of local media outlets, such as newspapers and community newsletters, to print press releases and safety columns,
- Inclusion of rail safety messages on routine mailings (e.g., utility bills),
- Training of public works in communities (e.g., police officers and firefighters), to be Operation Lifesaver presenters to provide a consistent safety message,
- Operation Lifesaver presentations, and
- Town hall meetings to highlight grade crossing safety and trespass prevention program.

Enforcement

- Use of positive reinforcement to reward compliance, such as coupons for coffee,
- Routine patrols along the railroad right-of-way to prevent trespassing,
- Focused enforcement at “hot spots” with a high rate of traffic violations,
- Trooper on the Train program so that members of law enforcement and the judiciary could see what locomotive engineers routinely experience, and
- Specialized training for law enforcement and first responders who investigate or respond to collisions.

The effectiveness of the education and enforcement program was measured via video surveillance, which captured train movements at eight grade crossings in three Illinois communities (Arlington Heights, Bartlett, and Macomb) 2 months prior to the initiation of the program, for 1-year during the program, and for 2 months after. Although data was collected from three communities, the video from only one of those communities was analyzed (Arlington Heights). In that community, the education campaign consisted of 122 presentations that reached at least 3,730 individuals over the 1-year period. Approximately 512 hours of enforcement accompanied the education program; this enforcement resulted in the issuance of 83 citations and 234 warnings. Of the citations issued, 72 percent were to drivers who violated the warning device, 11 percent were to pedestrians who violated the warning device, and the rest were to trespassers and for other grade crossing violations.

Observers viewed the video recordings to identify and count the rate of warning device violations. The violations were classified into three groups according to severity:

- Type 1A: violations in which the flashing lights were activated but the gate arms were up,
- Type IB: violations in which the lights were flashing and the gate arms were descending, and
- Type 2: violations in which the lights were flashing and the gate arms were lowered.

In first considering the Type 1A violations, the results showed a rate of 0.46 violations per train before the campaign, 0.48 violations per train during the campaign, and 0.53 violations per train after the campaign – an overall increase of 15 percent. For Type 1B violations, observations recorded 1.40 violations per train before the campaign, 1.10 during the campaign, and 1.00 after the campaign, an overall reduction of 29 percent. For Type 2 violations, observations recorded 0.78 violations per train before the campaign, 0.36 during the campaign, and 0.22 after the campaign, a drop in 72 percent. Thus, while the results showed an increase in the rate of Type 1A violations, the education and enforcement programs succeeded in reducing the more serious Type 1B and Type 2 violations (Sposato, Bien-Aime, and Chaudhary, 2006).

Feedback from the Illinois communities noted the challenge in finding the appropriate balance between education and enforcement. With respect to education, the sustained use of the local cable access programs and town hall meetings helped keep the safety message active for residents over time. Although enforcement techniques did not deviate from traditional enforcement of traffic laws, it did change the public's perception of the acceptability of violating active warning devices, which had previously gone without punishment. The results of Illinois' program provide a framework that may be adapted to other communities.

The studies discussed so far demonstrated the benefits of education alone (e.g., Operation Lifesaver; see Mok and Savage, 2005, and Savage, 2006) and education in conjunction with enforcement (Illinois Commerce Commission, 2005; Sposato, et al., 2006) on grade crossing safety. However, none of these studies measured the impact of implementing an education program alone versus the use of education and enforcement in combination. Tarawneh, Virendra, and McCoy (1999) examined this issue to determine the relative contribution of enforcement to enhancing the benefits of education in a safety campaign to deter red-light running. In their study, driver behavior was observed at six signalized intersections before and after the implementation of a safety campaign. The campaign educated drivers on the hazards of running red lights using 30-second public-service announcements on television and radio, print ads supporting enforcement efforts, safety brochures mailed with utility bills, and truck signs presented on city vehicles. At three of the six approaches, enforcement was present. Enforcement occurred at one intersection at a time, with the schedule of enforcement randomized so that drivers could not predict when and where the officers were likely to be. The results showed the campaign had a positive effect in modifying the behavior of drivers who approached the intersections after the yellow onset and that vehicles' mean entry time into the intersection after the onset of the yellow light decreased significantly after the campaign. However, there was surprisingly no difference in behavior due to education alone versus education with targeted enforcement. One possible explanation is that drivers were generally more conservative after the campaign, because they were aware that enforcement was present but did not know where it was, so they may have simply assumed that all the intersections at which driver behavior was observed would also be enforced. Note that it is not clear whether the results of Tarawneh, et al. are generalizable to other situations and domains since differences in the design and implementation of safety campaigns may change their impact considerably. Additionally, different approaches to enforcement may not have the same impact, an issue that will be examined further.

6.3 Enforcement

Enforcement of grade crossings can occur via one of two methods: a traditional traffic stop, in which a law enforcement officer witnesses a violation and issues a citation to the driver in person; or automated photo enforcement, in which violations are detected via a sensor and captured on film and the appropriate law enforcement authority issues a citation via mail. The first method, traditional traffic enforcement, is difficult at grade crossings where law enforcement presence may not be feasible due to the large number of crossings and relative infrequency of trains at those crossings and where pursuit of violators requires committing the same violation and risking a collision with an approaching train (Bowman, et al., 1998; Fitzpatrick, Bartoskewitz, and Carlson, 1997).

The second method, the use of automated photo enforcement to gather evidence of violations, is relatively new at grade crossings but has been more commonly used in general highway driving to improve compliance to traffic laws. In the US, the use of red-light cameras has reduced crashes by approximately 40 percent. The public recognizes its safety benefits; more than 75 percent of residents polled in cities *with* cameras and over 70 percent of residents polled in cities *without* cameras favored the use of automated photo enforcement to prevent red-light running (Insurance Institute for Highway Safety, 2001). However, several issues need to be addressed with respect to its implementation at grade crossings. First, because the photo enforcement system "observes" drivers to determine if a violation occurs, privacy concerns have been raised. For the most part, these concerns may be alleviated through public education campaigns that highlight the safety benefits and objectives of automated enforcement or by designing the automated enforcement system so that it does not photograph the driver (e.g., by capturing an image of the vehicle's rear license plate). Whether an image, that does not capture the driver, contains sufficient information to issue a ticket depends on the state and leads to the second issue. Who receives the ticket: the owner of the vehicle or the driver? This decision will depend on whether the citation is treated as the equivalent of a parking ticket or as a moving violation. Because moving violations result in "points" on the violators' license, conclusive evidence of the driver committing the violation will be required. The third issue regards whether or not citations may be mailed. In some states, allowing for this method of distribution may require legislation (Carroll and Warren, 2001; Fitzpatrick, et al., 1997; Turner and Polk, 1998).

No studies have compared the effectiveness of traditional enforcement versus photo enforcement, but the success of the enforcement method will be a function of how drivers perceive it. Enforcement must be visible. In the general driving situation, parking a police car in a highly visible location improved driver compliance to speed limits and reduced the average speed of traffic not only at the site of enforcement but also at locations downstream and upstream of the enforcement site (Hauer, Ahlin, and Bowser, 1992). Additionally, drivers must perceive a risk and believe that the enforcement agent will be able to apprehend them. For example, a police car positioned at the downstream side of a grade crossing that allows pursuit of violators as they exit the crossing may be more effective than a police car stationed before the tracks. Finally, enforcement efforts must be publicized. The effectiveness of this publicity will be improved if campaigns continuously educate the public, are continuously highlighted by news coverage, and prevent the public from expecting a level of enforcement that cannot be maintained (Shinar, 1985).

Six states in the US—Arkansas, California, Illinois, Iowa, North Carolina, and Texas—and the province of Alberta in Canada have conducted demonstration projects of automated photo enforcement at grade crossings. The remainder of this section discusses the implementation of photo enforcement, the issues encountered, and the results of evaluations examining its impact on driver compliance.

6.3.1 Arkansas

The city of Jonesboro, Arkansas, in conjunction with BNSF Railroad installed and tested the first automated photo enforcement system in the US in 1991. In the evaluation, video cameras were installed at one grade crossing that had experienced eight collisions in the past 5 years. Drivers frequently knocked down the gates at the crossing; prior to the installation of the photo enforcement technology, the gates were repaired an average of three times per week.

Video cameras at the grade crossing transmitted real-time images via a standard telephone line connection to the Jonesboro Police Department. Citations for violations were issued through the mail. Violations at grade crossings were treated similarly as parking violations; violators received a letter detailing the statute that authorized citations to be issued to registered vehicle owners, the citation itself, and two photos of the violation. The local judge also required a time-stamped picture of the motorist driving around the gate, a zoomed-in view of the license plate with clearly legible characters, and a time-stamped picture of the train passing through the intersection.

No warning signs were presented to inform drivers of the use of photo enforcement. Instead, a media campaign was conducted to increase the public's awareness. After one year, city officials reported that they had issued 10 citations and drivers had knocked the gates down only six times. Conversations with city officials indicated that most of these violations occurred immediately after photo enforcement was implemented (Fitzpatrick, et al., 1997; Lammert, 1999).

6.3.2 California

The Los Angeles County Metropolitan Transit Authority implemented the use of photo enforcement at grade crossings along the Los Angeles Metro Blue Line. The Metro Blue Line corridor is unique in that it contains tracks for commuter trains and freight trains, and two trains often cross at the same time or cross very close to one another. Consequently, gates at the crossings are often lowered for an extended period of time or begin to rise and quickly lower again, and as a result, many drivers violated the gates or ignored the flashing light signals. In the 3 years from the corridor's opening in July 1990 through June 1993, 158 grade crossing incidents occurred.

The use of photo enforcement was evaluated in three demonstration projects along the Metro Blue Line corridor. Drivers, who violated the crossing gates, activated cameras, and photos captured the vehicle, license plate, and driver. Superimposed on the photo was the date, time, location of the violation, vehicle speed, and number of seconds from the activation of the warning device. Citations were issued based on the photos within 72 hours of a violation.

The first demonstration of the technology took place at one grade crossing over a seven-month period. Comparison of the violation rate before and after its implementation showed that the use of photo enforcement decreased the number of violations by 92 percent, reduced the rate of violations from one per hour to one every 12 hours, and decreased the number of train-vehicle collisions by 70 percent. At a second crossing, the impact of photo enforcement was measured over three months with similar results. The number of violations decreased by 78 percent, and the rate of violations was reduced from a rate of one every 2 hours to one every 9 hours. At the third demonstration site, photo enforcement captured vehicles that made illegal left turns across the tracks against a red left-turn arrow. In a 6-week period, the number of left-turn violations dropped by 34 percent.

The success of photo enforcement at these three crossings led to the installation of the technology at 17 more crossings, with signs at the crossings notifying drivers of the use of photo enforcement. Additionally, the California vehicle code was modified to legalize citations recorded by photo enforcement. These citations are subject to the same procedures as those for moving violations (Carroll and Warren, 2001; Vantuano, 1994).

6.3.3 Illinois

In 1996, the Illinois General Assembly required the Illinois Commerce Commission to conduct a two-year evaluation to determine the effectiveness of photo enforcement technologies. Three locations were selected based upon an accident analysis of collision frequencies. Although the specific technology differed at each site, each system generally used the same process: a camera, started upon activation of the warning device, recorded potential violations, and these violations were reviewed using specialized software packages to identify actual violations and to determine which violations should receive citations. In order to issue a citation, a clear image or photograph of the vehicle, driver, and vehicle registration plate with a record of the time, date, and location of the violation was required. Crossings with photo enforcement had signs to indicate that the grade crossing was under surveillance, and that citations for violations would be issued, and that specified the amount of the fine. Citations were automatically generated using custom software and sent to registered vehicle owners. Citations were issued only to non-corporate owned vehicles registered in Illinois and were dismissed if the registered owner was not the driver when the violation occurred.

The results of evaluations of photo enforcement at three crossings showed that it was effective in deterring grade crossing violations. The first site to complete installation of a photo enforcement system (on Irving Park Road in the city of Wood Dale) reported a 47 percent reduction in violations per month over a 9-month period. At a second site (in the city of Naperville), the use of photo enforcement reduced violations by 73 percent over a 5-month period. At a third site, only one violation was recorded during the observation period before the automated enforcement system was installed and none after. Although no conclusions could be drawn regarding the effectiveness of photo enforcement at this location due to the limited number of observations, the low daily traffic and low violation rate during the observation period suggested that the use of automated enforcement might not be justified at the location.

It is worth noting that a procedural issue stopped the use of photo enforcement in the city of Wood Dale during the demonstration period. There, a local judge identified a problem concerning the issuing of citations at Irving Park Road and ruled that the notice for informing violators of their rights and responsibilities and the process for admitting digital images into evidence was not sufficient. As a result of the ruling, the local police department in the city of Wood Dale began to issue only warnings to drivers who violated the crossing. Since that time, the Illinois General Assembly has issued a state statute to clarify the admission of photos as evidence, and the city of Wood Dale hoped to resume the issuing of citations (Laffey, 2003).

6.3.4 Iowa

Officials from Ames, Iowa, the Iowa Department of Transportation, and the FHWA conducted an evaluation on the use of photo enforcement in 1996. The crossing selected for the evaluation experienced heavy volumes of train and vehicle traffic (50–60 trains and approximately 20,000 vehicles per day). In the 5 years prior to the evaluation, three accidents were attributed to drivers maneuvering around lowered gates.

The project included a public education campaign to initiate the program and to feature the system in the local news media. Additionally, signs were provided at grade crossings to indicate the use of photo enforcement. Iowa state law required a high-resolution picture of the driver of the violating vehicle in order to issue a citation and prohibited the mailing of traffic citations, so once the violation was verified and the citation process completed, a police officer hand delivered the citation to the violator's home. City officials decided to issue citations only to drivers who violated the grade crossing a few seconds after the gates were lowered. Motorists who drove around gate arms after they had been lowered for an excessive amount of time were not considered to be in violation because it was hypothesized that the protection system had malfunctioned; these drivers were sent a warning letter by mail.

The results of the demonstration project in the first year of the evaluation noted problems in the pictures taken of violations. Pictures taken during the day were not of sufficient resolution for identifying the driver. However, because the pictures had enough resolution to indicate the license plate number, violating drivers were sent warnings. On the other hand, pictures taken at night were not of sufficient resolution to read the license plates and the drivers' face was often obstructed by glare, so no violations were issued (Fitzpatrick, et al., 1997; Lammert, 1999).

6.3.5 North Carolina

North Carolina evaluated the use of photo enforcement at one crossing with a high-train volume (approximately one every 15 minutes) and a history of violations and incidents along its High-Speed Rail Sealed Corridor (the evaluation of median barriers, four-quadrant gates, and longer gate arms along this corridor was discussed in Section 3.1.3.2). The camera captured photographs of drivers, vehicles, and their license plates, and law enforcement and judicial officials prosecuted violators. The results showed a 72 percent reduction in gate violations over the 5-month demonstration period at the crossing (Carroll and Warren, 2001; FRA, 2002).

6.3.6 Texas

In 1995, the 74th State Legislature of Texas passed legislation that required the Texas Department of Transportation to investigate the use of automated enforcement at up to 10 gated crossings. To determine which crossings would benefit most from automated photo enforcement, Carlson and Fitzpatrick (1999) conducted a study to identify operational and geometric variables that influenced violations at gated grade crossings. In the study, they observed and recorded drivers at 19 grade crossings in Texas. Three categories of violations were defined based on the time in which the driver crossed the tracks. *Flashing light violations* occurred between the times the lights were activated and two seconds after the gate arms started to descend and accounted for 47 percent of all violations. *Typically enforced violations*, defined as (1) the time period after the gate arms were in motion more than 2 seconds and lasting until the arms were horizontal or (2) the time period after the gate arms were horizontal but before the train arrived, accounted for another 47 percent of the violations. Finally, *after the train violations*, violations occurring after the train departed but before the gate arms were completely raised, were the most infrequent of the three, and accounted for only 5 percent of the violations (Carlson and Fitzpatrick, 1999).

From the 19 grade crossings, six sites were selected for the demonstration of photo enforcement. A signal from the grade crossing warning system activated the photo enforcement system, and cameras at the crossing recorded vehicles continuing around or through the gate arms. The images showed the vehicle, a close-up of the rear license plate, the location of the crossing, the date and time of the violation, and the number of seconds before the train's arrival time. The demonstration project did not allow for the issuing of citations, so drivers, who violated the warning device, were sent educational material instead. The results of the demonstration showed no difference in the violation rates at three of the six grade crossings. The other three sites experienced technical or coordination difficulties. Although no difference in the violation rate was observed, this finding could be attributable to the fact that drivers did not perceive a risk of enforcement since citations were not issued. The implementation of appropriate fines in conjunction with education, as used in other states, may result in a more positive safety impact (Fitzpatrick, et al., 1997).

6.3.7 Alberta, Canada

Transport Canada sponsored a pilot study of automated photo enforcement and equipped one crossing in Strathcona County, protected by flashing lights and bells only (i.e., no gates) with video cameras (English and Murdock, 2005). Owners of violating vehicles received warning citations by mail with two images. The first image showed the vehicle prior to its crossing the stop line with the flashing red lights activated, and the second showed the vehicle violating the crossing. Both images showed the date and time of the violation and the time since the activation of the flashing lights. The second image also indicated the vehicle speed and the time interval from the first image.

To increase the public's awareness to the system, Strathcona County and the Royal Canadian Mounted Police distributed an information card about the system to drivers who frequently used the crossing, installed two signs on each of the approaches one week prior to issuing warning citations alerting drivers to the presence of the system, and conducted a media campaign. The campaign consisted of a news release describing the pilot project and interviews with the Royal Canadian Mounted Police.

Measures of the effectiveness of photo enforcement consisted of a before and after comparison of the violation rate. When citations were issued, the number of violations in which drivers failed to stop at the crossing dropped by 53 percent, and the number of violations in which the drivers stopped and then proceeded through the flashing lights dropped by 10 percent. However, some drivers exhibited unsafe behavior after the introduction of photo enforcement by moving into the lane of oncoming traffic to bypass vehicles stopped at the crossing or to avoid the detection loops installed in the highway. Detectors placed on both entrance and exit lanes to the crossing could reduce these violations.

6.4 Summary

The specific policies and actions of regulators influence safety at grade crossings. The impact of social and political forces can be seen in the enactment and subsequent repeal of whistle bans to achieve a balance between safety and the interests of neighboring communities. The FRA conducted several studies that showed whistle bans had a detrimental effect on safety and increased the accident rate at night in most communities (FRA, 1995a, 1995b, 2000, 2003), but residents continued to be concerned about the negative impact of the train horn on their quality of life. While the Final Rule repeals the majority of whistle bans, it does allow for the establishment of Quiet Zones and the use of alternative technologies, such as wayside horns, to pacify communities.

Public education also improves grade crossing safety. Statistically, Operation Lifesaver has had a significant nationwide impact (Mok and Savage, 2005), but the implementation of the program and its success varied from state to state (US GAO, 1995). The benefits of education may also be short-lived if it is not continuous. In Iowa, for example, a short public information campaign showed some success in improving drivers' approach behavior to the crossing after 1 month (Brewer, 1992), but observations of driver behavior 6 months after the campaign suggested the need for continuous education to effect more permanent changes (Iowa Department of Transportation, 1992). Additionally, education should consider the social aspects of driving (e.g., pressure from peers and other drivers to commit violations as noted by Parker, et al., 1992, 1995 and Wilde, et al., 1971), and drivers' beliefs regarding their accident risk and skill level (McKenna and Lewis, 1991). A public education campaign can be incorporated successfully with enforcement to improve driver compliance (Illinois Commerce Commission, 2005), although the benefits of education with enforcement versus education alone are not clear (Tarawneh, et al., 1999).

The use of enforcement alone at grade crossings may be implemented via the traditional traffic stop or via photo enforcement. While no comparison of the effectiveness of the two has been made, the methods used by traditional enforcement may not be feasible at grade crossings where there are a large number of crossings, a low frequency of trains, and where pursuit requires committing a violation (Bowman, et al., 1998; Fitzpatrick, et al., 1997). The use of photo enforcement is promising, with positive impacts reported from demonstration projects. In particular, in the states of California and North Carolina, the rate of violations dropped by more than 75 percent at crossings with photo enforcement (Carroll and Warren, 2001; FRA, 2002; Vantuano, 1994), and in Illinois, the rate of violations decreased by almost 50 percent (Laffey, 2003). Transport Canada reported similar benefits in a pilot study conducted in Alberta; the introduction of photo enforcement decreased the rate of violations at the crossing by an average of 69 percent (English and Murdock, 2005). However, the effectiveness of photo enforcement will be limited based on how the tickets are adjudicated, as judges in some states do not allow photo enforcement to be admitted as evidence (Laffey, 2003). The success of any enforcement strategy will be improved by its visibility, drivers' perception of its effectiveness, and publicity.

7 Summary and Conclusions

Although safety at grade crossings has improved in the past 10 years, driver noncompliance, attributable to error, risky driving behavior, or poor judgment, remains a significant problem. Lerner, et al. (1990) first addressed this issue in a comprehensive review that explored noncompliance as a result of human information processing limitations, errors in decision making, impairment, and the driver's inherent characteristics. A review of the literature since the publication of Lerner, et al. highlighted the fact that many of the issues discussed in 1990 are still relevant to the grade crossing problem today.

This review used a sociotechnical model to examine driver noncompliance at grade crossings. This approach allowed the consideration of factors pertaining not only to the grade crossing environment and driver but also to the influence of federal and state agencies and local municipalities and the forces exerted by the public. The review was organized in the framework of a sociotechnical system, shown in Figure 1, with four components. The innermost layer contains elements of the grade crossing environment: traffic control devices, the crossing layout, and trains. Moving out from the center of Figure 1, the next layer addresses characteristics of the driver with respect to skill and choice of driving style. Improvements to the grade crossing environment require coordination among public agencies, railroad companies, and highway authorities, as described by the third layer of the sociotechnical system. The outermost layer addresses the influence of social forces, such as public support or opposition to regulations and actions taken by regulators (Moray and Huey, 1998).

This document reviewed the literature addressing the topics in each of the layers of the sociotechnical model, as summarized below. Negotiating a grade crossing is only one component of the driving task, so this review included literature examining driver attitudes in the general driving task and applied it to the grade crossing domain. Following the summary, this section lists areas where further research is needed. Operational recommendations based on the results of the literature review are provided in Appendix A.

7.1 Summary

The *technical/engineering system* component, discussed in Section 3, describes characteristics in the design of traffic control devices (e.g., signs, pavement markings, and active warning devices) at grade crossings and the train that influence driver compliance. The findings of the literature review indicate that:

- Drivers generally recognized the advance warning and crossbuck signs but did not know where they were located in relation to the crossing, when the signs were used, and the action that was required.
- Proposed alternative sign systems typically included the presentation of a stop sign or a yield sign in conjunction with the standard crossbuck. The MUTCD allows the use of stop or yield signs at passive crossings where two or more trains operate daily (FHWA, 2003). The NTSB (1998) recommended the use of stop signs at all passive grade crossings because it would provide consistent information at grade crossings and clearly convey the action required, but this recommendation has been controversial.
- Observations showed that compliance with stop signs at grade crossings was low, and the results of an accident analysis indicated that the collision rate at stop sign protected

crossings were higher than that at crossings protected by other warning devices (crossbucks, flashing lights, or gates). In light of concerns that indiscriminate use of the stop sign at grade crossings could lead to noncompliance, FHWA (2006) clarified their position on the MUTCD provision by recommending that the yield sign be considered the default traffic control device for passive grade crossings and limited the stop sign to unusual situations where requiring vehicles to make a full stop was determined to be necessary by an engineering study or judgment.

- Use of the yield sign or incorporating a yield message into the sign system is more promising than use of the stop sign. Systems incorporating the yield message improved driver understanding of the action required relative to presentation of the crossbuck alone, but its effect on driver behavior, as measured through looking behavior, was mixed.
- Other proposed alternative sign systems discussed in the review distinguished active from passive crossings or alerted drivers to the possibility of a second train at the crossing.
- Little research has addressed the design of pavement markings since the publication of the Lerner, et al. (1990) report. Instead, research conducted examined the use of supplemental markings to provide drivers with information about whether there is safe storage for their vehicle beyond the grade crossing. Results showed these markings had limited success. Their effectiveness depended on characteristics of the site, such that larger benefits were found at crossings with few signs and markings relative to "busier" intersections where the markings could be missed among other crossing-related signs, markings, and signals.
- Observations of behavior at active grade crossings indicated that drivers were quite willing to violate active warning signals. This review discussed two methods for improving compliance: *explicitly* by providing barriers to prevent drivers from violating the crossing or *implicitly* by improving the credibility of the warning signals. Explicit methods include the implementation of four-quadrant gates, median barriers, and vehicle arresting barriers. Implicit methods include the use of constant time warning systems that reduce waiting time, identifying signal malfunctions to reduce the false alarm rate at the crossing, or incorporating highway traffic signals that have high credibility and compliance in the general driving situation.
- Noncompliance at crossings may be due to a failure by the driver to detect the grade crossing. Illumination of the crossing, using strobe lights in conjunction with signs at the crossing, and reflectorization of the crossbuck and crossbuck post facilitated detection, particularly in low illuminations. To optimize the use of reflectorization, the MUTCD requires the application of reflective sheeting on the front and back along the full length of the crossbuck posts to facilitate detection as well as reflectorizing the crossbuck (FHWA, 2003).
- Trains are equipped with alerting lights, reflective markings, and a train horn to facilitate their detection at a grade crossing. Regulations regarding their use are provided in three documents:
    - *Railroad Locomotive Safety Standards: Clarifying Amendments; Headlights and Auxiliary Lights; Final Rule* (codified in 49 CFR § 229)

- *Reflectorization of Rail Freight Rolling Stock; Final Rule* (codified in 49 CFR § 224)
- *Use of Locomotive Horns at Highway-Rail Grade Crossings; Final Rule* (codified in 49 CFR § 222 and 229)

Findings from field tests showed the effectiveness of alerting lights and reflective markings; participants detected trains equipped with these devices at further distances than trains equipped with the headlight alone or nonreflectorized trains, respectively. Additionally, the results of accident analyses noted the benefits of alerting lights and suggest the potential for the use of reflectorization to reduce accidents in which a vehicle runs into a train. With respect to the use of the train horn, acoustic tests showed the train horn was most audible when mounted at the front of the train. However, its effectiveness will be limited by the dampening of its sound (e.g., from community noise or interior noise in vehicles) and is of particular concern. Several studies evaluated the use of wayside horns, mounted at the crossing, and reported that they had no negative impact on safety while at the same time, reduced the noise level for residents in nearby communities.

The effectiveness of safety improvements at the technical/engineering system level must be evaluated with respect to the *personnel system*, the driver, as discussed in Section 4. Characteristics inherent to the driver relate to his/her skill level and choice of driving style, as summarized below.

- Driving skill is impaired by aging, lack of experience, internal or external distractions, or driver impairment.
    - With aging, changes in perceptual and cognitive abilities hinder the ability to detect cues to grade crossings and respond in a timely manner. For example, reduced visual acuity hindered the ability to detect signs and pavement markings at grade crossings, and less accurate estimations of speed and distance led to misjudgments of a train's arrival time at the crossing.
    - Lack of experience, particularly for young drivers, resulted in a less than efficient visual search strategy and underestimation of potential driving hazards.
    - The effect of driver distractions and impairment due to alcohol use or fatigue has similar consequences. Drivers may not realize they are approaching a grade crossing or fail to detect an approaching train. These two factors were significant contributing factors to highway accidents, but the increased risk at grade crossings is not known.
    - Countermeasures to compensate for reduced driving skill, in particular the effects of aging and experience, include techniques for facilitating detection of the crossing at night (e.g., reflectorizing trackside objects) and installing additional signs at the crossing to indicate the action required.
- Driving style, which is a drivers' choice of how to drive, influences the perception of the dangers at grade crossings and the decision whether or not to comply.
    - Drivers do not expect to encounter a train at a grade crossing and sometimes do not even look for a train. This behavior is partially attributable to familiarity with

an area, such that drivers who are familiar with a crossing are *more* likely to be involved in a grade crossing incident than drivers unfamiliar with the crossing.

  - Some drivers are also risk takers and find noncompliant behavior, such as beating a train across the tracks, exciting. Studies showed that risk takers understood the consequences of their actions but were overconfident in their driving skill and optimistic in their abilities to avoid an accident. Risk-taking behavior was encouraged by social factors such as peer pressure and the perceived acceptance of that behavior.
  - Drivers' attitudes were moderated by gender differences and age. Male drivers committed more violations and were involved in more grade crossing accidents than female drivers, and young drivers were more aggressive than older drivers. Noncompliance for males and young drivers was attributable to less concern with the negative outcomes of committing the violations than their counterparts, the perception that the risk of negative outcomes was not likely, or a sense that committing the violation was out of their control.
  - Changes to driving style are more difficult than changes to driving skill because they require a change in drivers' attitudes. Information campaigns that highlight the negative consequences of committing violations, reduce the perception of peer approval for committing violations, and emphasize self-control to resist committing violations may be beneficial.

The implementation of countermeasures to improve safety at grade crossings will require coordination and collaboration among federal, state, and local agencies. Decisions by different organizations regarding the design and structure of grade crossings impact the selection of which crossings to improve and the selection and implementation of countermeasures, as described by the *organization/management system* layer and discussed in Section 5. Some examples are presented below:

- The FRA requires the assistance of states and railroads to maintain their crossing inventory and accident/incident database of public and private grade crossings. Input is provided through voluntary submission, and reviews of the information in the database found that a significant number of grade crossings were missing and information regarding the warning devices at crossings was missing or inaccurate.
- Coordination between public agencies, railroad companies, and highway engineers may be necessary to determine which crossings to improve and what those improvements should be. Additionally, public discussions may be necessary to address any concerns about the impact of the changes on traffic, the neighborhood, and the public's convenience.
- Signal preemption to prevent traffic queues at intersections near crossings from extending into the grade crossing requires coordination between railroad companies, local and state transportation departments, light rail transit agencies, and regulatory authorities. Poor communication has resulted in problems integrating highway and rail traffic control devices. Additionally, joint inspections by the appropriate rail and highway authorities may be necessary to ensure continued compliance of the interconnected system.

- Several states have collaborated with railroad companies and industry to develop, implement, and evaluate the use of ITS technologies. These systems include in-vehicle displays to alert drivers to the presence of grade crossings and approaching trains, variable message signs located along freeways to inform drivers of approaching trains at crossings near freeway exits, so drivers can select alternate routes, and "intelligent grade crossings" where intelligent rail and automotive technologies are integrated. The effectiveness of these systems depended on their accuracy and drivers' perceived reliability of the system. Drivers did not trust systems that had a high rate of false alarms perceived them to be unnecessary and, when used at active grade crossings, redundant with the warning device.

The outer layer of the sociotechnical model, the *environmental system*, addresses the influence of public support and specific policies and actions by regulatory authorities to improving grade crossing safety. Components of this layer include the development of federal regulations and education programs and the use of enforcement, as discussed in Section 6, and summarized below.

- Notice of the FRA's development of regulations requiring the use of train horns at grade crossings was confronted with significant public opposition. Previously, state and local laws mandated rules regarding use of the train horn, and many communities established local whistle bans prohibiting the sounding of the train horn. The FRA conducted several accident analyses examining the effect of whistle bans in specific states and nationwide and found that these whistle bans had a significant negative impact on safety. Whistle ban crossings had an increased accident rate relative to crossings without whistle bans. In fact, the risk of a grade crossing accident increased by 84 percent when whistle bans were in effect. The one anomaly in the data was in the Chicago, Illinois area, where there was no significant difference in the accident rate at crossings with whistle bans compared to those without. As a result, the FRA developed regulation preempting all local whistle bans, with an exception for crossings in the Chicago Region, pending further data analysis. The Final Rule allows communities to establish Quiet Zones through coordination with railroad companies.
- The Operation Lifesaver program has had a significant impact in improving grade crossing safety nationwide by educating the public on grade crossing hazards. Education can be incorporated successfully with enforcement to improve driver compliance.
- Enforcement alone may be implemented via a traditional traffic stop or through automated photo enforcement. Several states in the US and one province in Canada have conducted demonstrations of photo enforcement and found positive impacts when its use was publicized and where consequences were tangible (e.g., through the issuance of fines).
- The actions by state legislatures and court system to adjudicate the rules of driver behavior at grade crossings must also be considered. For example, judges in some states have concerns about allowing photo enforcement as evidence, because it was not clear whether violators were sufficiently notified of their rights and responsibilities.

7.2 Areas for Further Research

The literature review addressed efforts to improve grade crossing safety, and identified areas where there are gaps in our understanding and additional research is needed. We propose the following topics for consideration.

- **Evaluate the use of highway intersection-related traffic control devices, in particular the use of stop and yield signs, at passive grade crossings.**

  As noted in Section 3.1.1.1, the similarities between driver actions at grade crossings and that at highway intersections has prompted interest in the use of stop and yield signs at passive grade crossings. The NTSB (1998) recommended the use of stop signs at all passive grade crossings because it clearly indicates the driver action that is required, but the recommendation has been controversial. Compliance with stop signs at grade crossings is low (Burnham, 1994; Lerner, et al., 2002), and there is concern that its use at grade crossings could foster disrespect for stop signs at traffic intersections. Thus, additional research is needed to examine the effectiveness of stop signs at grade crossings and empirically evaluate if the high rate of noncompliance at grade crossing stop signs could foster a general disrespect for the stop sign and carry over to non-grade crossing situations.

  The use of the yield sign has gained interest, but it has been evaluated in the field on a limited basis. The results of laboratory studies show that the use of the yield sign or a sign that incorporates the yield message improved comprehension of the action required. The results from field studies were mixed, but the studies had low sample sizes, so additional field data is needed to address its effectiveness.

  Traffic signals, which are less expensive to install than traditional active warning devices, may be applicable at grade crossings (see Section 3.1.3.3). In particular, the yellow light is expected to be useful to signal to drivers when there is a change in the right-of-way. Observations showed that the onset of the flashing lights resulted in rapid decelerations to the crossing, so the yellow light could improve safety by providing drivers with a sufficient warning. However, similar to the use of stop signs, there is concern that its use at grade crossings could impact its credibility at traffic intersections. Although traffic signals have been proposed as an alternative to traditional active warning devices, no empirical research has been conducted examining its use at grade crossings, but one study was identified, which found improved compliance with an enhanced traffic signal (Fambro, et al., 1989). Thus, additional research is needed to examine the feasibility of traffic signals at crossings.

- **Examine the use of traffic calming techniques at grade crossings.**

  Traffic calming techniques improve safety by discouraging inappropriate behavior through environmental modifications. This approach is similar to that proposed by ecological psychology, which focuses on the relationship between humans and their environment and examines how environmental design can modify human behavior by creating a perception of stronger or weaker affordances that in turn encourage or constrain certain actions. One example is the use of rumble strips at some grade crossings, which have been effective in alerting drivers to the presence of the crossing and reducing their speeds on the approach. However, its use may also promote unsafe behavior such that some drivers, aware of the presence of the rumble strips, swerve in the opposing lane to avoid them.

Other traffic calming techniques may be applicable at grade crossings and should be evaluated to determine their potential for encouraging compliance as well as their potential consequences. In particular, it will be important to determine whether the use of traffic calming technique to reduce speed upon approach to the grade crossing will divert attention away from the hazard at the grade crossing to the driving task of navigating the roadway.

- **Conduct a cost-benefit analysis to determine the impact of different factors that contribute to driving style.**

  Although the installation of active protection at grade crossings improves its safety, it does not guarantee compliance. Several studies have shown that some drivers are quite willing to ignore active warnings (Abraham, et al., 1998; Meeker, et al., 1997) and in fact, some found it exciting to "beat the train" (Witte and Donohue, 1998). Barriers at the crossing, such as four-quadrant gates, improved compliance, but these systems are expensive to install. Thus, it is important to understand factors that implicitly influence driver behavior at grade crossings.

  The decision a driver makes at a grade crossing is based on a weighting of costs and benefits. Factors that influence compliance may be internal to the driver (e.g., one's expectancy of a train) or external (e.g., the state of the warning device). The first step in the cost-benefit analysis is to understand what cues the driver uses in the decision whether or not to comply at a grade crossing, and then to model the costs and benefits of the cues (Edworthy, 2000). Understanding the contributions of different motivations can help determine which factors play significant roles in decision making at grade crossings and can be used to develop methods for improving compliance.

- **Examine methods for improving drivers' perception of signal reliability.**

  The effectiveness of countermeasures to influence drivers' perception of warning device credibility, discussed in Section 3.1.3.3, should be evaluated further. Drivers were more likely to commit a crossing violation as warning time increased beyond 20 seconds or if they perceived the signal to have a high number of false alarms (Richards and Heathington, 1990). No maximum warning time has been specified, but it is expected that reasonable and consistent waiting times by implementing constant warning time systems will encourage compliance (FHWA, 2002). While previous analyses comparing the accident rate at crossings with constant time warning systems to those at crossings with fixed distance warning systems found no difference between the two, it was not clear whether the results were due to limited data (Bowman, 1989) or to general driver distrust of grade crossing warning devices attributable to inconsistent warning times at fixed distance crossings (Halkias and Blanchard, 1989). Accident data collected in the time period since these analyses were conducted may speak to the effectiveness of constant time warning systems. Comparison of its use with fixed-distance systems should also examine its impact on safety along a rail corridor. Additionally, it may be worthwhile to determine if there are methods to reduce drivers' perception of waiting time, which is generally higher than the actual wait time.

The false alarm rate may be reduced through improvements in track circuitry and train detection equipment, the incorporation of good maintenance practices, and the identification and correction of signal malfunctions in a timely manner (FHWA, 2002). Continued research to identify the factors that contribute to drivers' judgments of signal reliability is needed. In particular, external cues, such as the sound of a train horn, presented in conjunction with a warning signal, may help drivers discriminate between reliable and unreliable warnings (e.g., see Gil and Multer, in preparation). Research should also address the effectiveness of auditory warnings when the warning comes from a wayside horn versus the train horn and the impact if the auditory warning is not available (e.g., in a quiet zone). Other external cues should also be considered.

The combined effect of these external cues with the signal provided by the warning system can be examined using the framework of distributed team signal detection theory. The theory proposes that an operator (in this case, the driver) and warning system are a team, working to reach a joint decision to optimize their performance (Lehto, 2006). Changes in performance by one team member can be used to alter the decision criterion for the other to optimize overall team performance (Lehto, 2006). In other words, while an understanding of the cues a driver uses to assess the warning signal's reliability (e.g., visual or auditory cues providing information about the presence of a train) can provide insight into how a driver determines whether to proceed or stop, observing drivers' compliance at crossings could also help warning designers determine how stringently to set the decision threshold for the warning system. Research exploring the applicability of this model of decision making to driver behavior at grade crossings is needed.

- **Conduct further research in the use of ITS technologies.**

  Several states have examined the use of ITS technologies to alert drivers to the presence of crossings and trains at the crossing. Many of these evaluations were conducted at crossings where the technology had little impact; for example, at active grade crossings where the in-vehicle warning was redundant with the active warning device, or areas where traffic was not significantly affected by the presence of a train at a crossing. Additionally, in most of the studies, the systems were evaluated subjectively, through user questionnaires, so little objective data is available regarding the impact of these technologies on driver compliance.

  Additional research is needed that examines the effectiveness of in-vehicle warning displays on compliance at passive crossings. Because drivers' subjective preferences are not always consistent with performance results, objective data regarding the use of ITS technologies would be valuable. In particular, it will be important to examine drivers' perception of the reliability of the information and the level of reliance on the in-vehicle warning display. It is possible that use of this automation will reduce drivers' looking behavior at grade crossings such that drivers will no longer perform an adequate visual search for approaching trains or other hazards due to over-reliance on the automation (Caird, et al., 2002).

- **Evaluate different approaches to educating drivers.**

  The positive impact of public education on improving grade crossing safety, and in particular the effectiveness of the Operation Lifesaver program, was noted in the literature review (Illinois Commerce Commission, 2005; Mok and Savage, 2005, Savage, 2006). Finding the right balance in developing an education program to improve grade crossing safety is challenging. The implementation of education campaigns differ, and even the success of Operation Lifesaver varies from state to state, due to variations in funding levels and available resources.

Traditional methods of education, while effective, may not be enough in the near future where new media technologies are changing how information is transmitted. New methods utilizing the Internet and other resources for engaging drivers should be considered (Secretary of Transportation, 2004).

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APPENDIX A: Guidance Summary

This appendix provides a summary of the recommendations from the literature review. The recommendations are based on federal regulations and research on countermeasures to improve driver compliance at grade crossings. The appendix is intended to provide operational guidance for the implementation of countermeasures and can be used as a quick reference or checklist. The section of the literature review where more detail can be found is provided in brackets following each recommendation.

A.1 Technical/Engineering System

The technical/engineering system addresses the design of the grade crossing environment and techniques to assist the driver in detecting the crossing and train. More detail can be found in Section 3.

- Although the Manual on Uniform Traffic Control Devices (MUTCD) allows the use of a Stop or Yield sign in conjunction with the crossbuck at passive grade crossings, concerns that indiscriminate use of the stop sign could lead to noncompliance led the Federal Highway Administration to clarify this provision and recommend that the Yield sign be the default traffic control choice. Use of the stop sign is limited to unusual conditions when a full stop is determined to be necessary by engineering analysis or judgment. [3.1.1.1]
- Warning sign conspicuity is improved through reflectorization or by lowering the height of the crossbuck so that it can be better illuminated by vehicle headlights. [3.1.1.1]
- Supplementary signs may be used in conjunction with the crossbuck and advance warning signs to provide drivers and pedestrians with additional information about the crossing (e.g., to discriminate between active and passive crossings, provide warnings regarding site characteristics, or to notify drivers to the possibility of a second train's approach). [3.1.1.1]
- Compliance at active crossings may be improved explicitly by installing barrier systems, such as four-quadrant gates and median barriers, which prevent drivers from violating the crossing. [3.1.3.2]
- Maintaining reasonable and consistent waiting times and reducing false alarm rates through good track maintenance practices can implicitly improve driver compliance at active grade crossings. [3.1.3.3]
- Illuminating the crossing improves its conspicuity and may reduce the number of nighttime grade crossing accidents by facilitating driver detection of the crossing. Other successful approaches for improving conspicuity are to use "illuminated" signs or strobe lights at the crossing. [3.2]
- 49 CFR § 229 requires the use of alerting lights on a train to increase its conspicuity. Additionally, placing the lights in a triangular pattern allows drivers to estimate the train's speed and distance from the crossing. [3.3.1]
- 49 CFR § 224 requires the use of reflective materials on the sides of all trains and freight cars. With the exception of flat cars and tank cars, the retroreflective sheeting should be applied in a vertical or horizontal pattern along the length of the car sides, and the bottom edge of the sheeting should be as close to 42 inches above the top of the rail as possible. [3.3.2]

- 49 CFR § 222 requires that the train horn be sounded when trains approach and enter public crossings. The horn must have a minimum warning sound level of 96 dB at a distance of 100 ft (30.4 m) to the front of the train in the direction of travel. Exceptions are permitted under certain circumstances. [3.3.3]
- Wayside horns, located at the crossing, can be used to alert drivers to an approaching train. Wayside horns provide a sound level greater than or equal to the train horn on drivers' approach to the crossing, while still reducing community noise in surrounding neighborhoods. [3.3.3]

A.2 Personnel Subsystem (Driver)

The personnel subsystem addresses the driver's skill and the contributions of driving style to overall driving performance. More detail is provided in Section 4.

- Reflectorizing the crossbuck and crossbuck post, illuminating crossings, and providing and reflectorizing additional signs that indicate driver action may compensate for age-related perceptual decrements and lack of driving experience. [4.1.1, 4.1.2]
- Distractions or impairment due to alcohol-use or fatigue exposes drivers to the hazards at grade crossings, but the level of increased risk is unknown. [4.1.4]
    - Countermeasures to prevent alcohol-related traffic accidents may be implemented at the state or local levels. At the state level, countermeasures include lowering the legal blood-alcohol level, setting zero-tolerance laws for drivers younger than 21 years old, and providing legislation for immediate punishment for alcohol-related offenses (e.g., automatic license suspension). At the local level, public information campaigns, such as high school and college alcohol prevention programs and community initiatives to prevent drinking and driving, and emergency room interventions with patients injured in alcohol-related crashes can help reduce future drinking.
    - Fatigue-related accidents at grade crossings can be prevented by getting a sufficient amount of sleep, avoiding alcohol when tired, and limiting driving between the hours of 12 a.m. to 6 a.m. When a driver becomes sleepy, stopping and taking a short nap or consuming caffeine equivalent to two cups of coffee may improve alertness.
- Reasonable and consistent waiting times and low false alarm rates at active crossings can encourage drivers to comply. [4.2.1, 4.2.2]
- Public information campaigns to highlight the negative consequences of committing violations at grade crossings and to emphasize driver self-control to resist committing a violation may help reduce risky driving behavior (e.g., the temptation to "beat the train" at the crossing). [4.2.3]

A.3 Organizational/Management Behavior

The Organizational/Management behavior subsystem describes the coordination and collaboration required among federal, state, and local agencies to improve safety at grade crossings. This is addressed in detail in Section 5.

- States’ voluntary submission of information to the FRA crossing inventory and accident/incident database would improve the accuracy of these resources and allow them to be used to determine which crossings are in need of improvement. [5.1]
- A standardized accident prediction formula that includes all variables determined to be valuable in evaluating grade crossing safety would be beneficial. [5.1]
- The implementation of improvements to grade crossings is facilitated with proper coordination between states and local agencies, railroad companies, highway engineers, and the public. [5.1]
- The implementation of successful signal preemption requires coordination by the railroad companies, local and state transportation departments, light rail transit agencies, and regulatory authorities. In particular, both highway and railroad agencies must work together to ensure the appropriate timing of signals. [5.2]
- Driver use and acceptance of intelligent transportation system (ITS) technologies, such as in-vehicle displays that alert drivers to the presence of a train, is dependent on the driver’s perceived reliability of the system and the driver’s perception of whether the system is needed. [5.3]

A.4 Environmental Factors

Environmental factors constitute the outermost layer of the sociotechnical model. This layer examines the political, social, and cultural forces that influence safety, as discussed in Section 6.

- Implementing FRA regulations requires adequately balancing the needs of local communities, municipalities, state agencies, and railroads to address safety concerns and community quality of life issues. [6.1]
- Public education campaigns can information drivers of the dangers at grade crossings and the actions required. Short information campaigns may have some success, but improving driver behavior in the long-term may require continuous education. The campaigns should consider the social aspects of driving behavior and methods for changing drivers’ motivation and attitudes. [6.2]
- Photo enforcement is a more feasible alternative to identifying violators at grade crossings than the traditional traffic stop. However, the effectiveness of photo enforcement will depend on how the tickets are adjudicated in the legal system. [6.3]
- A successful enforcement strategy must be visible, perceived by drivers to be effective, and well publicized. [6.3]