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13. ABSTRACT (Maximum 200 words)

This document provides guidance recommendations and supporting material to assist designers and implementers of intelligent transportation system (ITS) applications related to highway-rail intersections (HRI). The guidance focuses specifically on roadway user human factors requirements associated with ITS as applied to HRIs. The guidance is intended to be of immediate help to practitioners but also to serve as a resource and impetus toward the development of consensus standards and other more formal guidance or specification. The document has four parts. Part I describes the purpose and scope and provides a human factors conceptualization of the roadway user. Part II provides an overview of ITS applications that have been implemented at HRIs. Part III presents general human factors guidance that cuts across various specific HRI applications, for topics such as message factors, roadside displays, in-vehicle displays, and displays for pedestrians. Part IV presents guidance for specific HRI applications, including train arrival warnings, advance information about the HRI, enforcement and control of vehicles, and light rail transit. Each guidance chapter provides background on the topic, an explicit statement of the major human factors issues, and a set of guidance recommendations (with accompanying rationale for each). This report includes over 130 guidance recommendations.

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METRIC/ENGLISH CONVERSION FACTORS

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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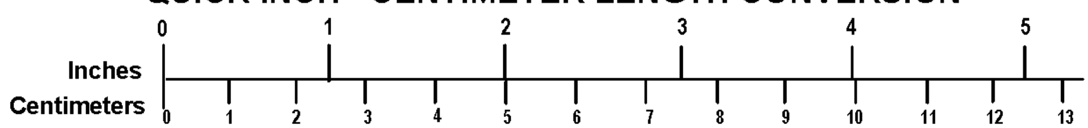
QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Preface and Acknowledgements

This document, *Human Factors Guidance for Intelligent Transportation Systems at the Highway-Rail Intersection,* provides guidance recommendations and supporting material to assist designers and implementers of intelligent transportation system applications related to highway-rail grade crossings. The document was developed under Federal Railroad Administration (FRA) contract DTFR53-00-R-00017. A final project technical report, *Human Factors Guidelines for Intelligent Transportation Systems at the Highway-Rail Intersection: Final Project Technical Report*, documents the primary activities and findings of the project. The technical report is available upon request from the project's sponsor, Dr. Thomas Raslear (thomas.raslear@fra.dot.gov).

This document is a revision that incorporates the comments of reviewers on an earlier draft. The project technical report includes a summary overview of the general findings of the reviewers. This version of the guidelines includes revisions in response to selected reviewer comments. It also includes footnotes that present selected reviewer opinions that may be of interest to readers.

The project team would like to thank Dr. Raslear and the staff of the FRA Office of Research and Development for support, guidance, and critical review throughout the course of this work. Important contributions were also made by the outside reviewers of the initial draft of this document. Reviewers were recruited from a range of technical disciplines and stakeholder groups. We thank these organizations for helping to distribute the request for reviewers:

- Transportation Research Board (Technical committees AHB15, AHB60, AND10, AND20)
- ITS America
- Association of American Railroads
- Operation Lifesaver
- Human Factors and Ergonomics Society (Surface Transportation Technical Group)
- American Association of State Highway and Transportation Officials
- American Traffic Safety Services Association
- Transport Canada

We gratefully acknowledge the outside reviewers who gave their time in reviewing all or portions of the document and provided many insightful comments. This acknowledgement should not be taken to imply that any individual reviewers endorse, approve, or agree with the contents of this document. The reviewers include:

- Patricia DeLucia, Texas Tech University
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Executive Summary

Intelligent transportation systems (ITS) technology can be applied to many transportation applications to improve safety and operations. Among the current and potential ITS applications are services related to the highway-rail intersection (HRI). The HRI is a point of potential conflict between rail and roadway traffic and, as such, is an important safety and operational concern. If ITS is to fulfill its promise, however, it is essential that the systems be designed with the human user in mind. The field of human factors specifically addresses issues of human interaction with systems. Although considerable human factors research and guidance for some ITS services has occurred, this has not been the case for HRI applications. No systematic effort to provide human factors standards or guidance for HRI ITS applications exists.

This document, *Human Factors Guidance for Intelligent Transportation Systems at the Highway-Rail Intersection*, provides human factors guidance recommendations and supporting material to assist designers and implementers of ITS applications related to HRIs. The guidance has a very specific focus on roadway user requirements that emerge for human factors issues associated with ITS as applied to HRIs. The guidance is intended for practitioners. However, the guidance may also be used as a basis for consensus standards and other more formal human factors guidance such as approved practices, industry guidelines, design specifications, regulatory policy, model applications, and so forth. Therefore, another purpose of this document is to serve as a resource and impetus for subsequent standardization, industry consensus, and formalization.

A set of key human factors issues was defined based on an extensive review of technical literature, expert contacts, reports of implemented systems, and analysis of guidelines in related fields. Guidance for the issues and applications was structured into a draft version of this document. A multidisciplinary group of potential users of the guidelines, stakeholder groups, and experts in relevant disciplines reviewed the guidance. Reviewers rarely disagreed with the guidance content. Revisions were made based on review comments and the document now includes selected reviewer comments as footnotes. These provide opinions and perspectives that may be of interest to readers.

The document has four parts. Part I (Introduction) consists of two background chapters. Chapter 1 covers the purpose of the document and scope of the guidance. Chapter 2 helps conceptualize the roadway user so that a proper perspective may be brought to human-centered design of ITS applications.

Part II, Overview of ITS Systems Implemented at the HRI, is a single chapter (Chapter 3) that describes the features and performance of ITS applications that have been implemented (usually as demonstration projects) at HRIs.

Part III, General Human Factors Considerations for Application of ITS to HRIs, and Part IV, Human Factors Considerations for Specific Applications, present the actual human factors recommendations. Part III (Chapters 4–7) presents general human factors guidance that cuts across various specific HRI applications, for topics including message factors, roadside displays, in-vehicle displays, and displays for pedestrians. Part IV (Chapters 8–11) presents guidance for specific HRI applications, warnings about train arrival, advance information about the HRI and dynamic route guidance, enforcement and control of vehicles, and light rail transit (LRT). In all, this report includes more than 130 guidance recommendations.

Each of the guidance chapters (Chapters 4–11) has a similar structure. The Background section describes the application and the relevant safety and operational concerns, and it reviews relevant research, practice, and field experience. The Key Human Factors Issues and Need for Guidance section identifies the major human factors issues of particular concern for the application and why guidance is needed. The Recommendations section provides the actual guidance statements with supporting discussions and rationales, as well as cross references to other sections of the guidelines and citations of key documents, where appropriate.

Part I: Introduction

1. Purpose and Scope

1.1 Purpose

ITS technology holds the promise of improved safety and operations for many transportation applications. The National ITS Architecture identifies more than 30 of these interrelated applications as user services, among which is the HRI User Service. Among the many listed elements and requirements of ITS for HRI in the architecture are those that require some form of communication with and management of the range of roadway users approaching and crossing the HRI. These road users include motor vehicle operators, bicyclists, and pedestrians.

Researchers and developers of ITS have clearly recognized that if ITS is to fulfill its promise and find public acceptance, it is essential that the systems be designed with the human user in mind. Products and systems that are not well understood, readily usable, and acceptable to the roadway users who encounter them can put the ITS enterprise at risk. A considerable amount of human factors research and guidance related to a number of ITS user services has occurred. This, however, has not been the case for the HRI, which was identified in the National ITS Architecture somewhat later than many other user services. Various specific ITS applications have been deployed, demonstrated, or proposed for the HRI. Where evaluations have been done, however, there frequently has not been a strong human factors component. No systematic effort to provide human factors standards or guidance for the HRI ITS user service has occurred.

The purpose of this document[1] is to identify the major roadway user human factors issues related to the use of ITS at HRI and to provide guidance for dealing with these issues. This guidance is designed for immediate use by practitioners. However, it is also seen a step toward the development of consensus standards. The recommendations and principles put forward here can provide a basis from which standards organizations, regulatory agencies, and a broad range of concerned stakeholders can work together to devise and promote standards. In fact, this document identifies, but does not address, some important human factors requirements. For example, one guideline recommends that the same standard icon be used to denote an HRI in all in-vehicle displays. The guidance identifies some of the attributes such a standardized icon should have. In the absence of a general industry practice or conclusive research studies, however, it would not be appropriate to promote a specific icon because the very point of the recommendation is that the stakeholder community comes to agree on a single icon. To identify the key human factors issues and develop recommendations, this work has made use of research studies, field evaluations, existing guidelines from other applications, and a range of expert contacts. This document attempts to provide whatever guidance the current state of knowledge and consensus permits while also indicating where critical gaps in knowledge and needs for subsequent consensus standards development exist.

1.2 Scope of the Guidance

The scope of this effort is restricted to the conjunction of the areas of human factors, HRI, and ITS (Figure 1). The human factors issues of concern in this document are those related to the roadway user, including passenger vehicle and motorcycle operators; operators of large vehicles,

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[1] This document incorporates revisions in response to selected reviewer comments on an initial draft. It also includes footnotes that present selected reviewer opinions that may be of interest to readers.

such as buses and tractor trailers; bicyclists; and pedestrians. Issues related to traffic control center/rail operations center, train crew, communications protocols, and maintenance operations, are not within this scope, but treatments exist elsewhere (e.g., Askey & Sheridan, 1996; Multer, Rudich, & Yearwood, 1998; Oriol, Sheridan, & Multer, 2004).

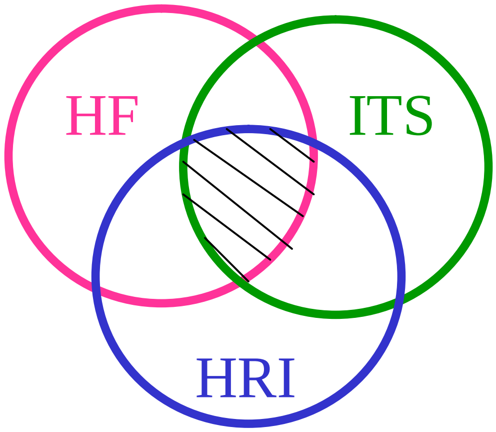


Figure 1. Scope of the project

Having recognized that this report focuses on the human factors of ITS applications for the HRI, it must be acknowledged that some human factors principles may be broadly important for all ITS applications, not just the HRI. These must be addressed to some degree, or this document will not serve its purpose of providing immediate guidance for HRI ITS designers and implementers. Such issues as display location, choice of modality, and so forth must be dealt with for any ITS application. While this document is not intended to be a general reference for human factors design, it discusses general principles to some degree.

Many human factors concerns are related to road user safety at the HRI, independent of any ITS component. A variety of reports and research studies over the past 25 years have addressed these concerns (e.g., Lerner, Ratte, & Walker, 1989; Mortimer, 1988; Dewar, 2001). Consensus standards groups and regulatory agencies have considered many of these issues in the development of current practice. The factors addressed by current standards and practice may be important to HRIs with ITS elements but not because of the ITS element. For example, features of automatic gates (markings, timing, etc.) should meet human factors concerns, regardless of whether the HRI is traditional or incorporates ITS. In this document, some unique aspect of the ITS application must exist in order to provide guidance here. General practices for HRI, which already reflect consensus or regulation, are not revisited in this document.

In summary, the scope of the recommendations provided in this report encompasses human factors requirements for road users related to ITS applications at HRIs. User-centered design is important for all types of HRI and for all human users within all component elements of ITS systems, but such general concerns are beyond this project's scope.

1.3 Human Factors Resources Related to ITS and to Road User Behavior

Although not a great deal of human factors research and guidance is directly related to ITS at the HRI, the human factors of other ITS applications have received more substantial resources. These are generally in the form of research findings or recommended practices, rather than as specific consensus standards. Because of interrelationships between user services and because shared design issues exist, these sources may also prove useful for HRI applications. The recommendations in this report draw upon human factors research from a variety of ITS applications and can also serve as direct references for the interested reader.

Two primary consensus standards organizations develop guidance for human factors issues in ITS. Established in 1991 to develop vehicle-related ITS standards, the Society of Automotive Engineers (SAE) Standards Division is responsible for developing industry consensus standards. SAE is involved in various ITS standards projects intended to produce standards and recommended practices that support system architecture, in-vehicle systems interface, advanced traveler information systems, and commercial vehicle operations, among other areas. Specific standards developed to date or currently under development include ITS In-Vehicle Message Priority; Operating Characteristics and User Interface for Adaptive Cruise Control; Operating Characteristics and User Interface Requirements for Forward Collision Warning Systems; Integration of ITS In-Vehicle User Interfaces; Navigation and Route Guidance Function Accessibility While Driving; and In-Vehicle ITS Display Legibility.

The International Organization for Standardization's (ISO) Technical Committee 204 is the lead international organization responsible for developing and harmonizing ITS standards across a broad range of ITS applications. ISO was founded in 1946 by 25 national standards organizations to bring together producers and users in the development of voluntary international standards. ISO has parallel efforts to develop standards related to transportation information and control systems, as well as road vehicle standards for ITS systems.

Research studies funded by National Highway Traffic Safety Administration (NHTSA), Federal Highway Administration (FHWA), and various States produced various guideline documents. These include the following:

- *Human Factors Design Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO)* (Campbell et al., 1998)
- *Preliminary Human Factors Design Guidelines for Driver Information Systems* (Green et al., 1995)
- *Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices* (Lerner et al., 1996)
- *In-Vehicle Display Icons and Other Information Elements: Final In-Vehicle Symbol Guidelines* (Campbell, Richman, Carney, & Lee, 2002)
- *Driver Information Demand Guidelines* (Lerner & Llaneras, 2000)
- *Guidelines for Changeable Message Sign Messages* (Dudek, 2002)
- *Developing Standards and Guidance for Changeable Message Signs in the Manual on Uniform Traffic Control Devices, Final Report* (Dudek, 2003)
- *The Development of Traffic-Information Web-Site Design Guidelines* (Nowakowski, Lenneman, Kojima, & Green, 1999)

In addition to these guidance documents, useful books on the human factors of driver behavior are also available, including some focused on ITS. Among these are the following:

- *Human Factors in Traffic Safety* (Dewar & Olson, 2001)
- *Human Factors for Highway Engineers* (Fuller & Santos, 2002)
- *A Policy on Geometric Design of Highways and Streets* (AASHTO, 2001; particularly Chapter 2, "Design Controls and Criteria")
- *Driving Future Vehicles* (Parkes & Franzen, 1993)
- *Human Factors in Intelligent Transportation Systems* (Barfield & Dingus, 1998)
- *Ergonomics and Safety of Intelligent Driver Interfaces* (Noy, 1997)

Two broad reviews of driver behavior at the HRI appeared in the late 1980s:

- *Driver Behavior at Rail-Highway Grade Crossings* (Lerner, Ratte, & Walker, 1989)
- *Human Factors in Highway-Railroad Grade Crossing Accidents* (Mortimer, 1988)

More recent, but narrower, reviews of specific HRI issues have appeared since these reports, but the fundamental human factors concerns remain the same. Westat (1999) provided a recent update of post-1989 literature specifically relevant to passive crossings and concluded that the issues remain largely the same and not much better understood.

1.4 Organization of the Report

Chapter 2 provides some context for considering the roadway user in the design of devices and systems for application at the HRI. A user-centered perspective is fundamental to good human factors design. Chapter 2 discusses some attributes of the road user that should be kept in mind for any application of ITS at the HRI.

Following Chapter 2, three general sections (parts) comprise the remainder of the document. Part II, Overview of ITS Implemented at the HRI, provides a brief review of ITS applications at the HRI with respect to Implemented Systems (Chapter 3). Part III, General Human Factors Considerations for Application of ITS to HRIs, identifies concerns and provides guidance for issues that may be related to a range of possible ITS applications for HRI. These considerations are organized under the headings of Message Factors (Chapter 4), Roadside Displays (Chapter 5), In-Vehicle Displays (Chapter 6), and Displays for Pedestrians (Chapter 7). These chapters address human factors concerns that must be confronted, whatever the specific application.

Part IV, Human Factors Requirements for Specific ITS Applications, identifies human factors concerns related to Warning About Train Arrival (Chapter 8); Advance Information About HRIs and Dynamic Route Guidance (Chapter 9); Enforcement and Control of Vehicles (Chapter 10); and Light Rail Transit (Chapter 11). Finally, the appendix lists all of the recommendations from Chapter 4 through Chapter 11.

Within these chapters, the general structure is to provide some background discussion on a given topic or application, followed by an explicit statement of the major human factors issues and need for guidance. This is then followed by specific guidance recommendations. Sometimes these recommendations can be quite specific. At other times, they can at this point only provide a general principle or set of limits. An accompanying Rationale Statement supports each recommendation..

Figure 2 shows the overall structure and interrelationships between guidance Chapters 4-11. The chapters are grouped into a rough hierarchy according to the level of generality and content of the recommendations. Chapters containing more widely applicable recommendations are positioned at levels closer to the top of the figure. The bi-directional arrows connecting the three levels indicate that similar or related recommendations in different chapters are cross referenced. Within the chapters, related recommendations in other chapters are within brackets; for example, the note [Also see: Recommendation 6-2] refers to Recommendation #2 in Chapter 6.

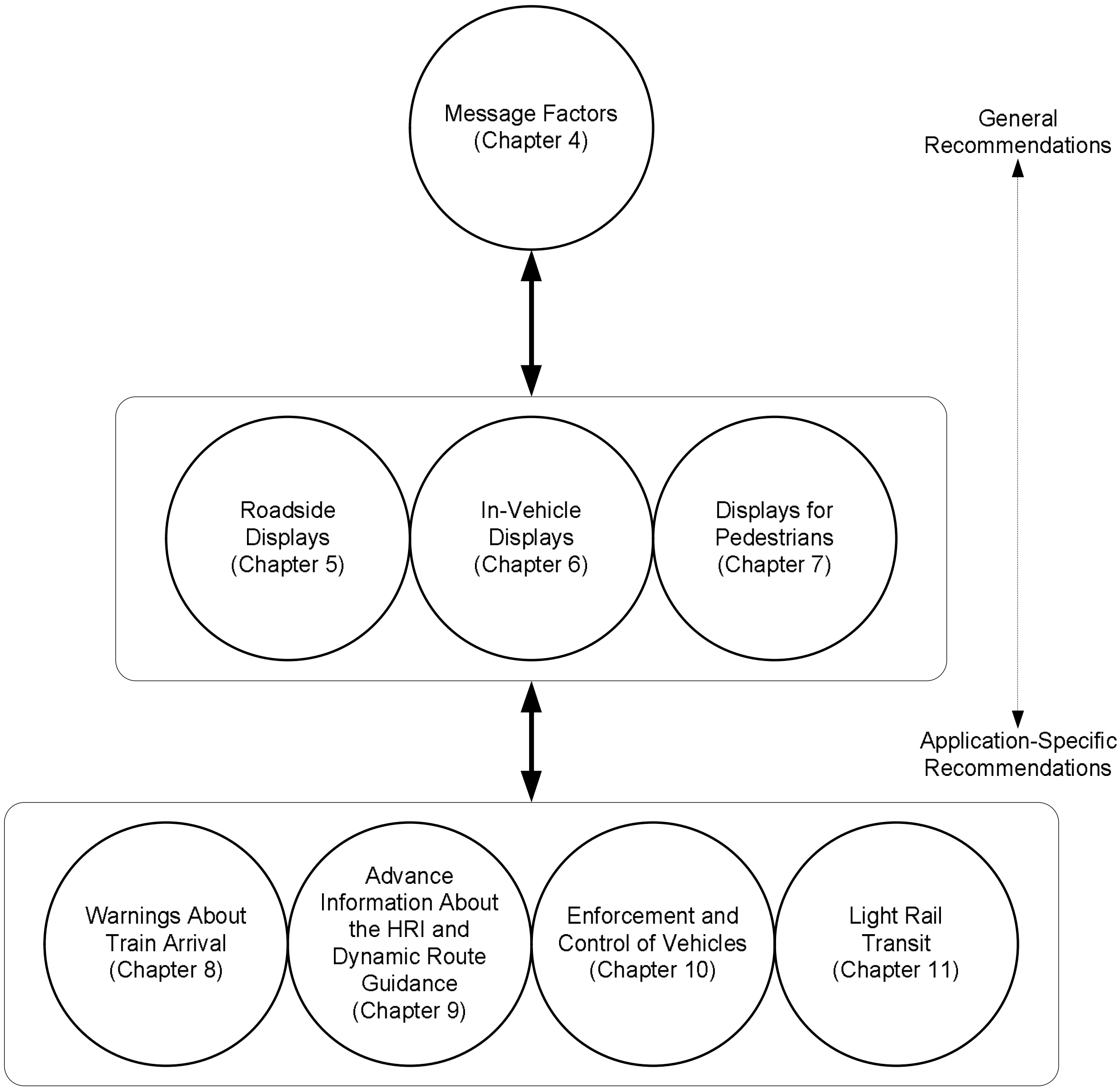


Figure 2. Guidance chapters (Chapters 4-11) and their interrelationship

2. Conceptualizing the Roadway User

2.1 Need for a User-Centered Design Perspective

The field of human factors addresses the interaction of devices or systems and their human users as these users engage in various tasks. Good human factors design requires an understanding of the characteristics of the users and the tasks in which they are engaged. ITS devices and systems, as with any application, should be designed in a manner consistent with the capabilities and behaviors of the range of people that will be using them. Furthermore, although the designer of the ITS device or system may have a specific purpose in mind, realization of that objective through design should be consistent with the road user's task as the road user understands it. The user-centered design philosophy is that an effective, safe, and accepted product is designed around the user. It takes into account not only physical and perceptual capabilities (such as reaction time or visual acuity) but also behaviors, knowledge, motivations, and attitudes. A good overview of the application of human factors in highway and vehicle applications may be found in *Human Factors and Traffic Safety* (Dewar & Olson, 2001), which also contains a chapter specifically on railroad grade crossings.

The behavior of roadway users is often complex and difficult to predict. They may not always respond to ITS information related to the HRI in the manner in which the designer intended that information to be used. Proper responding by road users requires that they do the following:

- Notice the display, in a reliable and timely manner
- Process the information being presented
- Comprehend the intended message and all of its implications
- Accept the validity and personal relevance of the message
- Choose to respond to the message, given the full range of (sometimes conflicting) tasks and motivations with which they are dealing
- Have the ability to execute the desired behavior in a safe and timely manner

This list of required steps is not meant to imply that the mental process underlying road user behavior necessarily runs off in this sequence. Real human cognition is much more complex and this is not intended to represent a model of road user cognition. The point is that each of the requirements above must be accomplished for the road user to ultimately act in the desired manner. The designer of an ITS device or system needs some understanding of the road users who deal with the HRI and who will be encountering the ITS display. Fundamental human attributes in perception and cognition that are relevant for the design of any display may be found in basic human factors references and are reflected in many of the ITS guidance documents cited in Section 1.3. Equally important, however, are the characteristics of roadway users that relate to their driving behavior, risk perception, and decisionmaking.

This chapter highlights some characteristics of the road user that are important for maintaining a proper perspective in the design of ITS and HRI applications. These characteristics may be incorporated in the guidance that is found in Parts III and IV of this document. It is also useful, however, to make these characteristics explicit, so that ITS developers can properly conceptualize the road users for whom they are designing.

2.2 Selected Characteristics of HRI Road Users

- *System context.* When developing an ITS traffic control device (TCD) or road user information system, a natural tendency to focus specifically on the interaction of the road user with the device exists. But this narrow focus is not necessarily how the world looks from the road user's perspective. For example, drivers may be concerned with maintaining the vehicle's path, monitoring other road users, monitoring other TCDs, searching for a landmark or sign, determining what lane they should be in, and so forth. They may also be attentive to non-driving features, such as looking at the surrounding area, conversation with passengers, attending to the sound system, and many other possible activities. An encounter with an ITS display is not an isolated event but occurs within the continuous flow of driving, where things may be constantly changing. The road user is always operating in a system with many demands and distractions, and no reason exists to assume that one particular device or display has a unique status. An ITS display has to function effectively within the system of roadway information, activities, and goals that characterize the road user. Research on driver behavior at the HRI suggests that road users often give little attention to the HRI in the context of normal driving. ITS displays, like other roadway-related devices, must be designed and evaluated for use as just one element in the system with which the road user is dealing.

- *Understanding of the HRI.* Roadway users do not always understand the meaning or implications of an HRI-related traffic control device, nor do they always understand their responsibilities at the HRI (e.g., Dewar, 2001; Lerner et al., 1989). Numerous examples of misunderstandings that can contribute to inappropriate behavior exist. These include the following:

  - Not understanding the specific meaning of such TCDs as the railroad advance warning sign, the railroad crossing sign (Crossbuck), various pavement markings, flashing lights, and automated gates. The public has a general understanding that these TCDs have something to do with the HRI, but the more specific meanings of devices are often not understood. Road users may also not fully comprehend the meaning of storage space signing and delineation near intersections or dynamic envelope delineation around the clearance zone of the tracks.

  - Poor appreciation of the different levels of protection at HRIs (gates, signals, passive) and misunderstanding of the level of protection at a particular crossing.

  - Inadequate understanding of the responsibilities of the road user at various types of HRI. These include the responsibility to search for conflicting rail traffic, the requirement to yield to trains in hazardous proximity, and the actions required, permitted, or prohibited by specific TCDs (gates, signals, stop signs, Crossbuck). Road users may not understand the responsibility to keep their vehicles out of potential conflict zones, such as storage space and dynamic envelope areas.

  - Poor appreciation of sight distance limitations and associated vehicle approach speed requirements, in general and for a specific HRI.

  - Limited understanding of the risk factors at the HRI. For example, many road users do not appreciate the limits to a train's ability to stop or the implications of multiple tracks. They may not recognize variations in train speed. They may also not recognize limitations to the reliability and accuracy of their own visual and auditory capabilities (e.g., judging speed and distance, hearing train horns).

- *Levels of the driving task.* Driving is not a unitary task but a collection of many different activities that the motorist must coordinate. Theorists who model or describe the driving task have conceptualized it in many ways, but a number of these models have agreed in characterizing driving task demands as falling into three hierarchical levels. Using the terminology of the Positive Guidance model (Lunenfeld & Alexander, 1990; Post, Alexander, & Lunenfeld, 1981), these levels are termed *control*, *guidance*, and *navigation*. Control tasks are related to basic driver control of the vehicle and its relation to the roadway and obstacles; this involves immediate control of speed, path, and direction. Guidance tasks are those tasks related to a driver's selection and maintenance of safe speed and path. While the control level deals with the driver's interaction with the vehicle, the guidance level is more related to decisionmaking and involves judgments and predictions about the upcoming situation. The navigation level involves planning and executing a trip, from its origin to its destination. In the Positive Guidance Model, these three task levels form a hierarchy based on the primacy of the information (that is, its priority for being dealt with). The control level has the highest primacy, and the navigation level has the lowest primacy. When providing ITS information or any form of information to drivers, it is important to design and locate the information display so that it is consistent with primacy requirements. Drivers who are dealing with time-critical demands for high-primacy actions must have those demands satisfied before they are confronted with lower primacy needs. This has implications for where information should be placed, how it should be sequenced, how it should be spread out, and how it should be related to roadway features.
- *Handling information. S*everal aspects of handling information should be noted. These include coping with the information load, integrating information sources, and the timing of information needs. Motorists often have to cope with a great deal of information while they are driving. This may include formal driving-related or HRI-related information from signs, signals, markings, and other displays. It may also include many other sorts of information, such as the features of the roadway; the features of the HRI, the actions of other traffic, and in-vehicle information displays; and information from many possible sources unrelated to driving. Processing this information—sorting it, attending to it, and interpreting it—takes time and effort. A road user must have sufficient time to process and respond to the information in an ITS display, under the real-world information environment in which it occurs. Some ITS displays have the potential to contribute to information overload for the road user. When motorists receive more information than they can process in the time available, various things can happen: "they may decelerate severely or drive too slowly, make late or erratic maneuvers, take an improper route alternative, ignore crucial information, fail to monitor other traffic, or have excessive episodes of eyes-off-the-road time" (Lerner, Llaneras, McGee, Taori, & Alexander, 2003). Information overload is a joint product of the demands of the information and the time available for dealing with it. Therefore, the designer of an ITS application must consider the demands of processing the information in the ITS display and how this fits within the general driving and information context in which it will be presented. Another aspect of information handling is the road user's integration of all sources of information.

The designers of an ITS display may consider their device to provide the information to which the road user should respond. To the road user, however, this may be only one of various sources of information. This information may come not just from TCDs, but from what is implied to the motorist by the appearance of the roadway, the appearance of the HRI, the actions of other traffic, and personal history and beliefs. The weight given to an ITS message will be influenced by how the road user perceives its accuracy and personal validity. Various studies have shown that user compliance with ITS information degrades as the accuracy and timeliness of the message declines (e.g., Kantowitz, Hanowski, & Kantowitz, 1996). Furthermore, people recognize that the assumptions or objectives of the designer may not be consistent with their personal situation, as they perceive it. For example, a driver may feel that a warning is based on the capabilities of less capable drivers or that the safety cushion is more extreme than necessary. Dynamic ITS displays based on real-time data therefore must protect their validity and convey a believable message to individual road users.

- *Expectancies*. People do not only respond to what is physically present at the moment, but also to what they expect the situation to be. Expectancies are based on long-term general experience (e.g., history of what a driver has encountered at HRIs), long-term specific experience (e.g., what a driver has encountered at a particular HRI in the past, what a driver has encountered from a particular device in the past), and short-term experience (e.g., characteristics of the road the driver has just been operating over). When the actual situation is consistent with the road user's expectancy, the way the road user responds tends to be quick and accurate. When a road user's expectancy is inaccurate, the way the road user responds tends to be slow and error-prone, and information may lack credibility. The implications of this are that the designer should (1) try to create the proper expectancy in the road user; (2) design the system to be compatible with likely road user expectancies; and (3) where inaccurate user expectancy is likely to occur, take additional measures to overcome this.
- *Personal optimization*. The designer of an ITS application will have the goal of optimizing safety and operational efficiency for train operations and/or roadway traffic. This is not the perspective of individual road users. They focus on their own goals, which may seem trivial when viewed from the designer's perspective. Time saving, impatience, frustration, and convenience may all drive individual decisions, even if the potential safety consequences would appear to be more critical concerns. This is sometimes referred to as personal utility. Optimization of individual concerns might influence how road users react to such factors as gate down time, preemption, or route recommendations.
- *Risk perception and risk management.* Road users base their actions on their perceived risk, which is not necessarily an accurate reflection of actual risk. Safety information about the HRI will be interpreted and evaluated based on the road user's personal feelings about risk and the quality and validity of the ITS information relative to other sources of belief. Furthermore, the road user's goal is typically not to minimize personal risk but rather to optimize all personal benefits, based on their personal criteria; safety is only one element of this equation. Another important aspect of risk behavior is that people often adapt their behavior to some potential safety benefit in a way that lets them take more risk. This phenomenon is termed *risk compensation*. For example, if drivers had an in-

vehicle warning about the presence of approaching trains at an HRI, they might compensate for this safety enhancement by driving faster through the site and engaging in a less visual search for trains. For this reason, the realized benefits of new roadway safety technologies are often not as great as research studies or initial evaluations suggest they would be.

- *Social context*. Although driving is an individual activity, road use does occur in a social context. The presence of other people can facilitate or inhibit various behaviors in road users. For example, if vehicles queue up behind a driver at an HRI, the driver may feel pressured to cross the tracks, even if he or she is unsure of the safety of the situation. If a driver prefers to slow adequately to search for trains while other vehicles do not, the driver may be made to feel overly cautious or as if he or she is a traffic obstruction. When some road user violates a TCD (e.g., going around a gate), this may facilitate similar behavior by subsequent road users. In some cases, local norms of behavior emerge (e.g., everyone knows you don't really stop at that particular HRI). One particular concern for ITS applications may be when partial penetration of an in-vehicle system in the vehicle fleet occurs. Some of the aspects of social interaction may be exacerbated if various road users are getting different information.

- *Attention and distraction*. A person's ability to simultaneously pay attention to different features of the environment is limited. This is a concern for all types of roadway users, although the problem is most acute for motor vehicle operators because of their higher travel speeds and greater stopping requirements. Different aspects of the driving task and various sources of information may compete for the driver's limited attention. The allocation of attention to different activities may be influenced by the momentary demands of the driving task, the timeliness and urgency of the information, and personal motivations. ITS displays ideally should be timed so that they are compatible with other driver information needs and do not mutually interfere with other driving task demands. Furthermore, drivers are often not fully attentive to the driving task itself. The ITS device and system developer should not work from the assumption that the driver is necessarily focused on the driving task. Recent research on driver distraction demonstrates that distraction is not unusual but rather quite typical of normal driving. For example, a recent study (Stutts et al., 2003) instrumented the personal vehicles of 70 volunteer drivers and videotaped their behavior for up to 10 hours of actual driving time. The experimenters recorded many different categories of potentially distracting activities such as eating, drinking, using a cell phone, and attending to things inside the vehicle. This study found that some distracting activity was going on nearly one-third of the time while the vehicle was in motion. About one-half of this distracted time was attributable to conversation with a passenger, while the rest was distributed across many types of distractions. The actual degree of distraction was not measured in this study, so these events may best be described as potential distractions. Nonetheless, this study indicates how common overtly observable behaviors with distraction potential, unrelated to driving, occur during typical travel. Of course, unobservable distractions (such as daydreaming or thinking about personal concerns) also occur and would add to this distracted time. No reason exists to assume this potential for distraction would be any less in the vicinity of an HRI. ITS design must therefore recognize that users of the device or system are quite likely to have their attention directed to unrelated aspects of the driving task and to non-driving activities.

- *Range of driver and vehicle capabilities.* Road users represent an extremely diverse population. First, the mode of transport varies, from pedestrians to bicyclists, motorcyclists, passenger vehicle drivers, and operators of large vehicles, such as buses and tractor trailers. These different classes of road user vary drastically in travel speed, stopping ability, acceleration, viewer's eye position, visibility of the roadway, noise environment, and driving task demands. Human factors aspects of ITS displays must encompass the full range of road user categories for which the application is intended. Second, within any of these groups, people will differ radically in terms of capabilities, knowledge, and experience. With the exception of commercial or public vehicle operators, only minimal constraints exist on who is allowed to use the roadway. Road users, therefore, vary widely in visual capabilities of many sorts (e.g., acuity, night vision, peripheral field, glare susceptibility, color vision), auditory perception (e.g., detection threshold, localization, speech perception), information processing ability, psychomotor skills, anthropometric characteristics, health pathologies, transient debilitations (fatigue, alcohol, drugs, emotional state), training, literacy, and driving history. The need to encompass this range of roadway users is not unique to applications of ITS at the HRI; it is important for any TCD application. However, because some innovative ITS technologies may lack the history of field application experience associated with traditional signs and signals, established criteria for broadly usable devices may be lacking. The designer should avoid a preconceived notion of the typical user of the technology and remain cognizant of the range of capabilities among road users.

2.3 Summary

Designing an effective ITS device or system for the HRI requires an appreciation of the capabilities, behaviors, motivations, and attitudes of the range of roadway users who may encounter the ITS display. The human factors aspects of design cannot be treated as a simple and direct transaction between the device and the road user, with the road user responding automatically in the manner envisioned by the designer. Road user behavior is more complex than that. There exist numerous models of various sorts that attempt to describe some aspect of driver behavior. However, no broadly accepted and sufficiently detailed model of the driver or other road user serves as an integrative scheme for characterizing the roadway user. This chapter highlighted some of the important behavioral characteristics of HRI road users as an aid in conceptualizing the target of ITS device and system design. ITS applications developed around an appropriately understood concept of the road user are more likely to be effectively used and accepted.

Part II: Overview of ITS Implemented at the HRI

3. Implemented Systems

This chapter briefly describes several ITS applications for HRIs that have been implemented in the United States. The chapter groups the applications under three headings: Information About Arriving Trains (Section 3.1), Multiple Train Warnings (Section 3.2), and Vehicle Control and Automated Enforcement (Section 3.3). In compiling this information, the focus is on applications that are targeted to the information and safety needs of roadway users. In several cases, lessons learned from the operation of these systems have shaped the human factors guidance given in the remainder of this document. Table 1, at the end of this chapter, highlights several key pilot studies and operational field tests of advance alert and warning systems, as well as other ITS implementations that support law enforcement and traffic control at HRIs.

3.1 Information About Arriving Trains

Advance information about approaching trains can be delivered to motorists through a variety of means, including in-vehicle systems (e.g., navigation units, stand-alone devices, highway advisory radio (HAR)), roadside changeable message signs (CMS), kiosks, Web sites, personal digital assistants, and cell phones. Information about train movements can also be incorporated into Traffic Management Center operations, enabling operators to alleviate effects of train activity on traffic by adjusting signal phasing and timing, dynamically implementing lane use or turn restrictions, recommending alternate routes via CMS, and coordinating with emergency services. Much of the work in this area has focused on enabling advance train detection (developing the technology and making it reliable, accurate, and feasible to implement).

A number of proof-of-concept studies examining alternative techniques, configurations, and architectures have been performed. Most notably, the Federal Railroad Administration (FRA) has sponsored a series of performance-based engineering evaluations of vehicle proximity alert systems that alert drivers to the presence of a train approaching the HRI (Carroll, Passera, & Tingos, 2001). The goal of the research program was to assess the feasibility and effectiveness of these systems for detecting trains at passive crossings. Test results showed that some system designs were able to reliably detect train direction and speeds, and they pointed to additional design issues and concerns to be addressed in future development efforts. This includes work to increase system reliability, reduce false alarms, tune the warning zone around the HRI to prevent nuisance alarms, design user interfaces, and develop human factors standards.

A number of systems designed to warn or alert motorists of approaching trains or trains occupying the HRI have been developed and field tested. Although these have varied along a number of key factors (type of information presented to motorists, the means through which information is communicated, size and scope, and the target users, etc.), these systems are generally designed to provide unique information beyond what is currently available at HRIs. Most of these systems have emphasized presentation of dynamic train information (train approaching, or at the HRI, train speed and direction, etc.). The following describes these systems.

3.1.1 Train Detection and Reporting Systems in Texas—College Station, Sugar Land, and Laredo

The Texas Department of Transportation (DOT) and Texas Transportation Institute (a research center of Texas A&M University) have collaborated to develop innovative systems to detect train movements and to report and predict HRI status information to transportation researchers and officials, emergency response services, and roadway users. Three such systems are Rail View in College Station, Rail Monitor in Sugar Land, and an unnamed rail monitoring system in Laredo.

Rail View was implemented along the Wellborn Corridor in College Station, Texas (Texas Transportation Institute, 1999; Trans-Link Train Monitoring Project, 2002). The primary purpose of this system is to provide real-time train movement information to emergency service providers, traffic management operators, and traffic signal controllers. Researchers also use Rail View data to improve traffic control systems near HRIs. The data provided by the system include train location, direction, speed, estimated times of arrival and clearance at downstream HRIs, and the duration that the train will occupy the HRI. This information is especially useful to emergency service providers who can use the Rail View information to choose a route that will not be blocked by a train. Real-time crossing information is available to firefighters on in-station laptops. The Rail View technology would also allow crossing information to be presented to emergency responders through in-vehicle computers, though this has not been attempted. Data are also available to the general public on Texas A&M University's Web site and through Web-enabled cell phones, though these media provide limited benefits to motorists and may cause driver distraction if used within the vehicle. Figure 3 shows the online user interface. At the lower left of the display is a low frame rate video image of one HRI on the corridor (video display is blank in Figure 3), and at the far right is a map of grade crossings in the vicinity. When a train is present in the rail corridor, the display also presents the train location, length, and speed, along with the estimated time of the train's arrival at upcoming grade crossings and the estimated time of the train's departure from grade crossings that it has passed. No train is present in the example shown in Figure 3. Rail View data can also be made available to motorists using CMSs and in-vehicle devices, though no such motorist information systems have yet been implemented or investigated.

The Texas DOT also implemented a train detection and reporting system in Sugar Land, Texas (Goolsby, Vickich, & Voight, 2003). The system monitors 6.4 miles of rail, which includes eight HRIs. Approximately 30 trains travel this corridor every day. The primary goal of the Rail Monitor system is to provide HRI status information to police, fire, and emergency medical services (EMS) to allow responders to avoid unnecessary delays at train-occupied HRIs. Information kiosks were provided for police and fire dispatch and for individual stations. The same information was also available to the public through the Houston Transtar Web site (http://traffic.houstontranstar.org/rail/). Train status information is updated in near real-time. As shown in Figure 4, the system information includes a graphic representation of HRIs along the rail line with icons to represent train presence and direction, train speed, length, and estimated time of arrival and clearance at downstream HRIs. Interviews with dispatchers and fire station officials indicated that these users found the system helpful and had confidence in its reliability. Like the Rail View system described earlier, Rail Monitor is not currently designed to aid typical roadway users, but future enhancements may make the HRI information available to

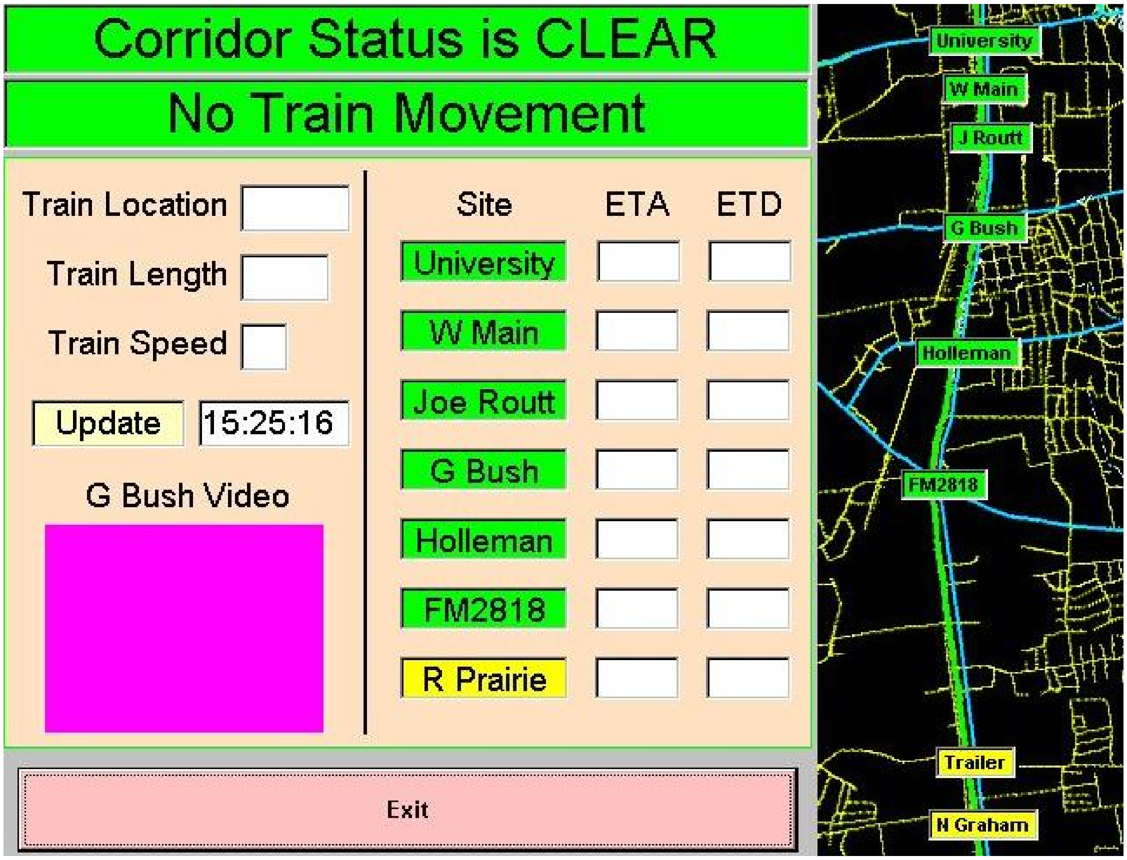


Figure 3. Rail View online user interface

roadway users using CMSs, HAR, or mobile wireless technologies, such as cell phones and pagers. Future enhancements may also include integration of train information with nearby traffic signals to improve signal timing and preemption.

In Laredo, Texas, drivers on Mines Road (FM 1472) often face long delays and heavy traffic as a result of frequent train crossings; each train may occupy the HRI for as long as 7 minutes (Texas Transportation Institute, 2001; L. Ruback, Texas Transportation Institute, personal communication, February, 2004). An existing system at the HRI used flashing lights on static signs to inform drivers in advance if a train was present at the HRI, but it did not provide drivers with any additional information. The new system still uses advance signs with flashing lights to alert drivers to train presence (see Figure 5), but it also triggers an automated message to play through an HAR frequency. The HAR message reports whether a train is present at the HRI, how long it has been present, and the direction it is traveling. Each message is about 10 seconds long and repeats continuously. The message is updated every 3 minutes, and messages are automatically generated from a prerecorded set of information. Despite the designers' goal of providing a bilingual message to accommodate the large Spanish-speaking population in the area, limitations of the existing hardware prevented this. Drivers can use the HAR information to choose a route that will not be blocked by the train, though the HAR message does not specify alternate routes. Designers envisioned the system as primarily benefiting commercial drivers, but other motorists may take advantage of the information as well. No evaluation has been conducted to assess the system's effectiveness.

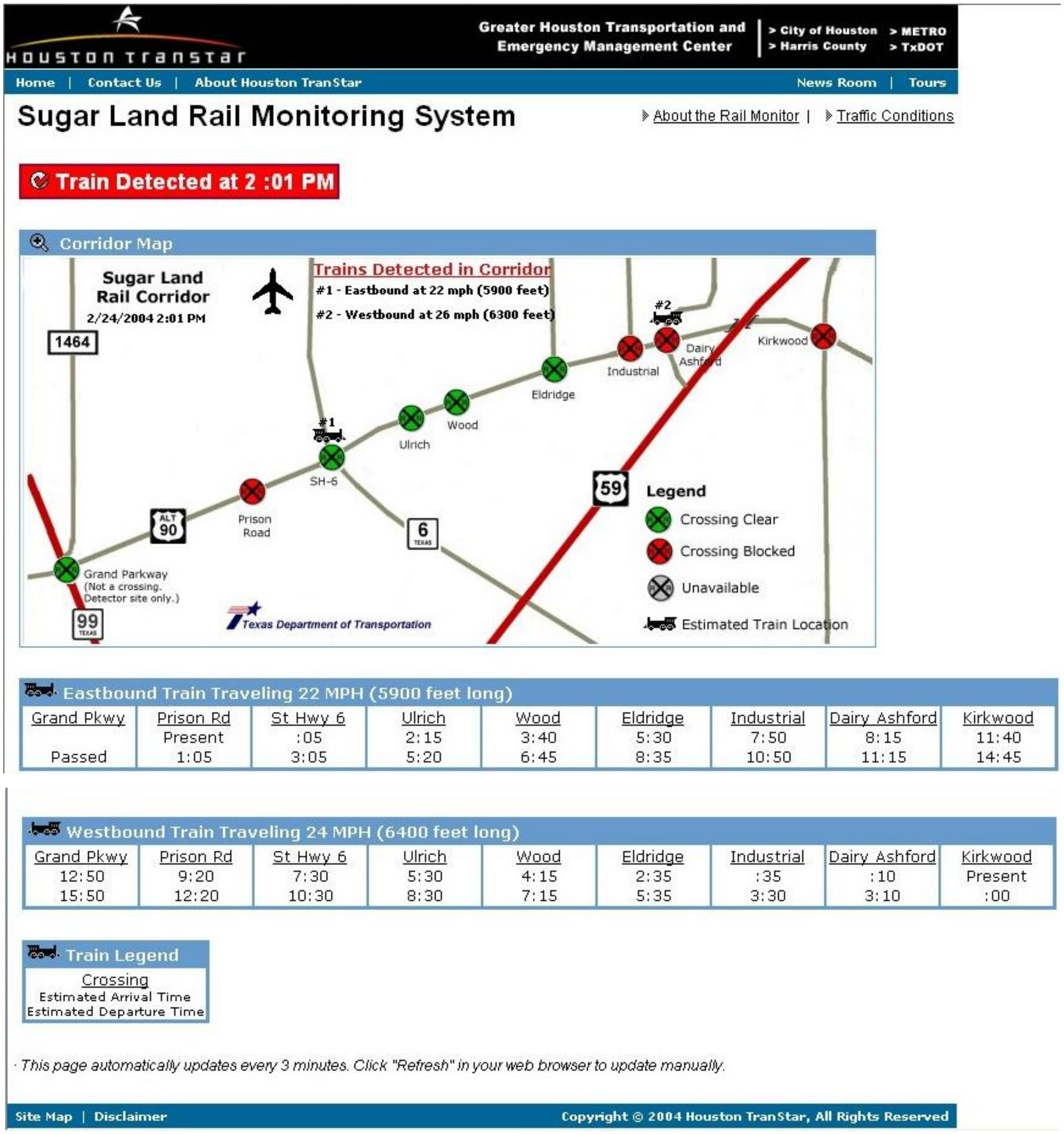


Figure 4. Rail Monitoring System online user interface

3.1.2 Advance Warning to Avoid Railroad Delays (AWARD)—San Antonio, Texas

The AWARD system uses ITS technology to detect and predict train arrival and HRI information (Federal Highway Administration, 2000, 2001; Carter et al., 2000). The information is also delivered directly to traffic management operators and emergency service providers, as well as being available to the public on the Web. This information is also presented to motorists via advance CMSs. The CMSs are intended to inform motorists traveling on the freeway when a train occupying an HRI near an upcoming exit is causing traffic backups. This allows drivers to select alternate exits to avoid delays. The system detects the presence of trains operating in affected areas and predicts the time and duration of the blockage of HRIs at or near freeway exits

Figure 5. Advance signs with train-activated flashing lights in Laredo, Texas

and entrances. Information is also presented using Advanced Traveler Information Systems (kiosks, Web, in-vehicle navigation systems, Traffic Management Centers, etc.) incorporated into the effort as part of the Metropolitan Model Deployment Initiative. Unfortunately, the system was never fully deployed, making it difficult to assess user satisfaction and system effectiveness, though subsequent simulation models estimate that travel time delays could be reduced nearly 20 percent for drivers who reroute around blocked HRIs. The Texas DOT continues to operate the AWARD system at six HRIs.

3.1.3 Moorhead Area Integrated Train Detection and Traffic Control System—Moorhead, Minnesota

The Minnesota DOT and the City of Moorhead, Minnesota, cooperated to develop this system that tracks train movements through the downtown Fargo-Moorhead area. Rail traffic on the Burlington Northern Santa Fe Railroad averages 50 trains per day through this area. The purpose of the system is to reduce motorist delay and improve emergency vehicle response (SRF Consulting Group, Inc., 2000). Initially, the system used video-based sensing, but, in a subsequent phase of the project, microwave-based sensors were added to detect train presence, speed, length, and direction. Train movements are predicted, and dispatchers can use this information to estimate time of arrival at each HRI. Traffic signals in the area were programmed with a train present timing plan in an effort to reduce traffic delays associated with train movements through HRIs. An independent evaluation did not find evidence for significant reductions in traffic delays following system implementation (Advanced Traffic Analysis Center, 2003). Some problems, however, exist with this analysis. Various technological problems caused a delay in the timeline for implementing the system, and this resulted in the before and after evaluation periods being spaced several months apart. The evaluators noted that traffic patterns changed during the study period, and the small amount of data collected limited the statistical power of the analysis. Despite problems with the evaluation, system implementers agreed that they did not realize substantial overall reduction in traffic delays. Problems with transitioning the traffic signal controllers to normal synchronization following the train present timing sequence diminished the potential benefits of the system on traffic flow. The train detection system is no longer connected with the traffic signal system (E. Minge, personal communication, August, 2004). In the future, the system may provide real-time train information to motorists, as well as emergency vehicle and transit operators and dispatchers. Motorists may be notified of delays associated with train movements through CMS located in advance of affected HRIs. These signs may display information such as the number of minutes that the nearest HRI would be blocked. (Results of a survey of area drivers suggested that a substantial percentage of drivers (74 percent) would re-route to avoid a 10-minute delay.)

3.1.4 Intelligent Grade Crossing—New Hyde Park, New York

The intelligent grade crossing (IGC) was developed by New York State DOT and Alstom Signaling (Chappell & Carroll, 2000; Federal Highway Administration, 2001; Grade crossing system tested at New Hyde Park, 2001). Although never actually implemented for use, system features were simulated at one HRI on the Long Island Railroad. This HRI has heavy rail traffic, typically more than 200 trains per day. Combined with heavy roadway traffic, trains can cause substantial delays for motorists. The IGC uses advanced train detection, vehicle detection, and communication equipment to improve roadway traffic flow, provide information to motorists, and enhance communications between train crews and the HRI. The system activates HRI lights and gates based on train speed and location and thus can provide a constant warning time of 27 seconds. This can result in an overall decrease in gate-down time and a subsequent reduction of motorist delays. The system also includes CMSs upstream of the HRIs to inform motorists of train status and, in conjunction with a queue detection system, to inform motorists not to cross the tracks if the queue is in danger of extending back onto the tracks. System descriptions, however, did not address specific messages. When long queues do accumulate, the IGC can turn the downstream traffic signal green to release the queue. If the system detects a vehicle stopped on the tracks, approaching trains are brought to a stop. The IGC also reduces gate-down time by allowing gates to remain up when trains are stopped at a station adjacent to the roadway. In the case of multiple train events, the enhanced train detection capabilities also prevent gates from beginning to rise after the first train passes, only to begin descending again once the second train enters the activation zone. By keeping the gates down during the entire multiple train event and providing a second train coming message on CMSs, drivers may be less likely to attempt to cross the tracks after the first train passes. The IGC also has a unique feature to accommodate emergency vehicles. While most ITS systems provide train movement information to emergency personnel to allow them to reroute, the IGC actually allows emergency personnel to communicate with the IGC and, if there is enough time, automatically bring the train to a stop before it obstructs the HRI.

3.1.5 In-Vehicle Signing System for School Buses at Highway-Rail Grade Crossings—Glencoe, Minnesota

This in-vehicle signing system presented alerts and warnings to bus drivers approaching HRIs (SRF Consulting Group, Inc., 1998). The system was installed on 29 buses in a Minnesota school district and was functional at 5 HRIs. The system provided two types of information: (1) a crossing alert, indicating proximity to an at-grade rail crossing and alerting drivers to the presence of the HRI and (2) a train warning indicating whether or not a train is present or near the HRI (approaching train warning). Alerts were presented in vehicles using icons, light emitting diodes (LEDs), and warning tones. The icons were meant to represent standard warning signs currently present at all HRIs. Presence of an HRI was communicated using the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) standard W-10 advance warning sign icon with two small yellow LEDS mounted in the upper and lower quadrants defined by the “x” of the sign (see Figure 6, left panel). Once the system detected an HRI, the yellow LEDS flashed in unison at a rate of four times per second, and an auditory tone was issued (runs 200 milliseconds (ms) of 1300 Hz tone, followed by 200 ms of silence, then 200 ms tone). Two repetitions of the tone were presented at initial detection. When the system detected an approaching train or one occupying the HRI, it issued a train warning via the standard Crossbuck sign graphic that included two red LEDs under the graphic (see Figure 6, right panel). The red LEDs flashed in alternation at a rate of 500 ms and were accompanied by an auditory signal (1900 Hz tone) that cycled 500 ms on, 200 ms off, 200 ms on, 200 off. The system emitted eight repetitions of the tone upon initial detection. After that, LEDs continued to flash, but the tones were silenced. Tones were repeated for each additional train warning signal (second train). The system was mounted in the center of the dashboard above the steering column to avoid obstructing the driver’s view of the dash controls, gauges, or mirrors.

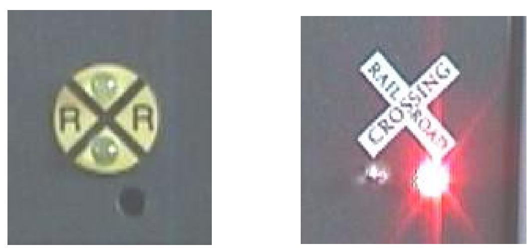


Figure 6. In-vehicle HRI display for school buses

The system provided a minimum of 250 feet of advanced warning (grade crossing/train presence) and possessed several unique features, including compensation for ambient noise to automatically adjust the volume over the surrounding in-vehicle environment and the ability to discern the direction the bus is traveling relative to the HRI. This avoids nuisance warnings when the vehicle is within the vicinity of the HRI but not intending to cross the tracks. In other words, the system was designed not to activate unless the vehicle’s direction of travel would take it through the HRI. A blue LED in the lower right corner indicated normal operation; the light flashed when the vehicle was in the presence of a transmitter signal. This feature enabled drivers to discern equipped HRIs from those not possessing this advance warning capability.

An evaluation studied the impact of the warning system on bus driver behavior (approach speeds, scanning behavior, etc.) and perceptions of the system (awareness of tracks, presence of train, driver confidence in system). Because of the small scale of the deployment, no actual crash data could be studied. No significant differences were found across these measures for performance with the system compared to baseline performance levels. Drivers were concerned that false alarms (alerts issued when not in proximity of an HRI or in the presence of a train) could erode driver confidence in the system. Interviews with bus drivers revealed that 80 percent of drivers believed that the system provided useful warning information, but only 15 percent of drivers felt that their driving behavior actually changed as a result. Interviews with train engineers suggest that the system may be more useful in commercial trucks than in cars because there appears to be more of a concern on their part for collisions with large commercial vehicles than passenger cars. All in-vehicle and trackside equipment is removed after the evaluation period, and the system is no longer in use.

3.1.6 Advisory On-Board Warning Systems at Railroad Grade Crossings—Metra-Milwaukee North Line

The Illinois DOT piloted an in-vehicle warning system designed to alert drivers of a train approaching or occupying an HRI (Benekohal, Aycin, Sikaras, Jonak, & Kennedy, 2000; Aycin & Benekohal, 2002). The Advisory On-Board Warning system was deployed at five actively controlled crossings along the Metra-Milwaukee North line. The deployment phase of the pilot study spanned 9 months and included more than 270 vehicles equipped with a commercially available in-vehicle receiver and display unit developed by Cobra Electronics. Study sites had moderately heavy train activity (between 70 and 115 trains daily) with commuter, Amtrak, and freight train movements. Drivers from 38 organizations participated in the study that included school buses, emergency, fleet, and commercial vehicles. The system was designed to supplement existing HRI warning systems (lights, gates, etc.) by providing an advisory warning of a train approaching or occupying the HRI and featured a warning zone range between 800 and 1,200 feet.

The in-vehicle unit (see Figure 7), installed within the driver's forward field of view, was capable of providing audio and visual warning messages. The form of the alert was varied as part of the pilot test and included audio only, visual only, or combination audio and visual modes. In the visual-only mode, text messages indicating "Caution" or "Warning Train" were issued in the presence of a train approaching or occupying the HRI (the caution message was only issued in situations where the unit was not 100 percent certain of a train event). In the audio-only mode, the system presented warning signals (beeps and tones) in the presence of a train approaching or occupying the HRI. The volume of the audio warning message was 15–35 decibels (dB) above the ambient noise level. In the combined audio and visual mode, drivers received both audible warning signals and text messages. The system continuously issues warnings for the duration of the train event and terminates once the train cleared the HRI and the active crossing controls (gates and flashers) ceased operation. Drivers also received training on how to operate the unit and interpret system messages. Results of the pilot showed promise, but a more reliable operating system is required for future deployments.

Figure 7. Advisory in-vehicle warning system

Summary: Information About Arriving Trains

Relatively little empirical data have been collected to assess impacts of train arrival warning systems on driver behavior and acceptance. Current evidence indicates that drivers prefer advance information that provides unique train status information (e.g., estimated arrival time, expected delay associated with train crossing) as opposed to systems that merely provide redundant information currently available at HRIs (signage and active traffic control device treatments). Furthermore, although status information is valuable to waiting motorists, the ability to re-route and avoid delays is an important benefit provided by these types of systems (see Chapter 9). Data also suggest that directionally sensitive systems (those capable of issuing warnings to approaching motorists only) may be better accepted than global systems that broadcast messages indiscriminately because they limit nuisance alarms; this is particularly crucial for in-vehicle systems. System reliability is a major factor for all types of implementations. To instill trust and have roadway users act on the information provided, systems must be perceived as accurate and reliable.

3.2 Multiple Train Warnings

A special need for train arrival warning occurs when more than one arriving train presents a hazard to the roadway user. This situation can be particularly dangerous because the first train may reduce the likelihood that the roadway user will be aware of the second train. The first train may block the view of the second train. It may mask the sound of the second train. It may draw the road user's attention away from the approaching second train. In many cases, drivers may not be expecting a second train event, making it even more challenging for them to detect and respond to the unexpected event. ITS technologies that provide specific information about train movements can be incorporated into systems that alert roadway users to the presence of multiple trains. A warning device used to alert roadway users to the presence of another train is known as a second train warning, or more generally, a multiple train warning (MTW). MTWs may be designed for motorist and pedestrian applications, typically for actively controlled grade crossings where multiple train events occur frequently with significant potential for collisions. Other considerations for the application of MTWs include traffic and pedestrian volumes, crash data or observations of risky behaviors, public comment, high train speeds and/or limited sight distances, mixed rail traffic (with varying speeds), the number of tracks, and geometry of the HRI.

No common practice has emerged for MTW implementation. While some signs are text only (Calgary Transit in Canada, San Jose LRT in California, and Joint Powers Board and Union Pacific lines in California), others are graphic only (Los Angeles Metro Blue Line (MBL) in California), or they include both text and graphics (Maryland Mass Transit Administration (MTA)). British Rail (Railtrack) combines a passive warning sign with a two-pitched auditory warning. When the second train approaches the HRI, the auditory warning increases in pitch to indicate that another train is coming. The passive sign is intended for motor vehicle operators and pedestrians, but the auditory signal is intended primarily for pedestrians.

For most of the MTW applications noted, the choice of display modality was apparently based on implementer preference or budget limitations, or at best limited to informal in-house testing with employees. Empirical testing with appropriate user groups was not part of sign development. Likewise, in most cases no reported followup studies to assess system effectiveness or message comprehension occurred. The systems implemented by the Los Angeles County Metropolitan Transportation Authority (LACMTA) and the Maryland MTA, however, did include such evaluations. The following sections summarize both demonstration projects.

3.2.1 Second Train Warning Sign Demonstration Project—Los Angeles, California

The LACMTA implemented an MTW at the Vernon Ave HRI on the MBL (PB Farradyne, 2002; Khawani, 2001; V. Khawani, Los Angeles County Metropolitan Transportation Authority, personal communication, December 2001). Figure 8 shows the HRI, with the warning display visible in the upper center of the photograph and a train entering from the right. This MTW is specifically intended for pedestrians. Track geometry, frequent multiple train events (approximately 25 per day), and large volumes of pedestrians contributed to make the Vernon Avenue HRI one of the most hazardous on the MBL for pedestrians. Multiple train events were factors in a number of vehicle-train and pedestrian-train collisions. Though no MTW was provided to motor vehicle operators, there were active warnings, including gates that minimized the potential for multiple train-related collisions on the roadway.

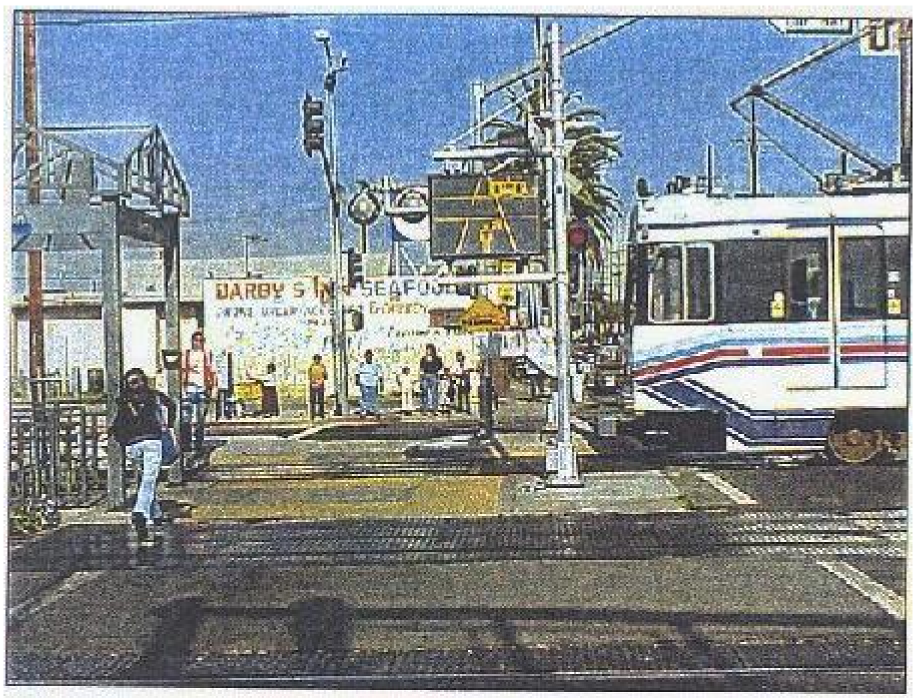
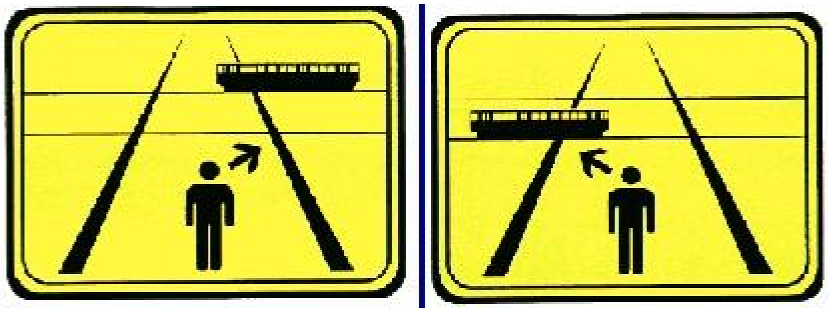


Figure 8. LACMTA MTW for pedestrians installed at Vernon Avenue grade crossing

The particular graphic signs used in this field test were selected following a series of development activities that included an expert workshop and field surveys with local area pedestrians. Graphic signs were better understood than the text-only signs, possibly because the text signs were presented in English despite a majority of Spanish-speaking respondents. The final graphic sign chosen (Figure 9) was a two-part display that, when activated, showed a simple line illustration of the HRI from the pedestrian's perspective. The first phase of the display showed an LRT train on the top track on the right-hand side of the display with an arrow pointing from the person to the train. The second phase of the display showed an LRT train on the bottom track on the left-hand side of the display with an arrow pointing from the person to the train. The sign is mounted on a standard mast arm on a platform between sets of tracks and



(Note: Actual sign has amber legend on black background.)

Figure 9. LACMTA MTW display (prototype)

is visible from both directions of approach. When no train is coming, the sign remains dark.

A survey of pedestrians near the HRI found that although 77 percent recalled seeing the sign, only 4 percent understood that more than one train was approaching. However, 92 percent interpreted that caution was necessary. The frequency of risky acts performed by pedestrians was compared before and after sign installation. The before period was the 11 weeks immediately preceding sign installation. The 9-week after period was spread out due to technical problems. Data were collected for 5 weeks beginning about 5 weeks after sign installation. Data were collected for another 4 weeks beginning more than 11 months after sign installation. Risky acts were defined as occasions in which pedestrians crossed the tracks with less than 15 seconds before a train arrived. The comparison found that risky acts decreased by 14 percent after sign installation. The decrease became more apparent when limiting analysis to risky crossings below 6 seconds (32-percent decrease) and risky crossings below 4 seconds (73-percent decrease), though there were only 19 total observations in the latter category. The assessment of sign effectiveness indicates that the MTW sign does reduce the likelihood of train-pedestrian collisions, but lack of understanding of the sign's meaning may limit the sign's potential to improve pedestrian safety.

Although the MTW remains operational, LACMTA has not implemented the sign at other HRIs (V. Khawani, LACMTA, personal communication, December 2001). The agency has installed pedestrian gates and swing gates that provide a physical barrier, as opposed to a sign, which it feels can be ignored more easily. However, on a case-by-case basis, it may consider circumstances that warrant a second train sign as a supplement to the gates. The agency feels there is a need for caution about providing too many signs, active displays, and other equipment at an HRI because it might result in confusion for the pedestrian or motorist.

3.2.2 Second Train Coming Warning Sign Demonstration Project—Timonium, Maryland

The Maryland MTA implemented an MTW at the Timonium Road HRI of the Baltimore Central Rail Line in Baltimore County (Maryland Mass Transit Administration and Sabra, Wang, & Associates, Inc., 2001; V. Hartsock, Maryland MTA, personal communication, December 2001). Unlike the sign in Los Angeles, the Maryland sign is primarily intended for use by motor vehicles, though standard incandescent Walk/Don't Walk signals were installed to aid pedestrian crossing the tracks. Though no serious collisions have occurred at the Timonium Road HRI, heavy roadway traffic and numerous daily multiple train events (approximately 10 per day) resulted in the location for sign implementation. Figure 9 shows the implementation, which supplements existing train-activated lights and gates.. The warning display, which remains blank unless a multiple train event is detected, is visible on the cantilever arm that supports the flashing signal lights (highlighted by a dashed circle in Figure 10), and a normal pedestrian crossing signal is visible at the sidewalk to the left.

Figure 10. Timonium Road crossing site with MTW

Principles developed by MTA and the Federal Transit Administration (FTA) regarding legibility, message content, message clarity, and sign location guided the design and implementation process. Based on these criteria, an FTA report on LRT signage, and the prototype signs developed by the LACMTA for the Vernon Avenue crossing, a committee of Maryland MTA experts developed three prototype displays for consideration. Two were three-phase displays with text and animation; the only difference between the two was the order of the phases. The third was a single animation incorporating both text and graphics. MTA managers were shown all three signs as they would appear on the final sign, and they showed a strong preference for the three-phase display shown in Figure 11:

- *Phase 1:* Flashing "WARNING" text for 2.5 seconds
- *Phase 2:* Steady "2nd TRAIN COMING" text for 2.5 seconds
- *Phase 3:* Simple graphic display of HRI (roadway intersecting with tracks from vehicle operator's perspective) with animation of two trains crossing road from opposite directions for 4 seconds

Figure 11. Maryland MTA MTW display

The total duty cycle of the sign is 9 seconds. The sign remains active from the moment that a second train activates the HRI warning devices until at least one full cycle has been completed and all trains have cleared the gate activation circuits. Two signs were installed, one for each direction of traffic. Each sign was installed on a cantilever arm overhanging the roadway. An amber beacon was installed adjacent to each sign. When the MTW sign is activated, the beacon flashes to draw motorists' attention to the sign.

Investigators measured the frequency of various specific risky behaviors performed by vehicles and pedestrians in the month immediately before sign installation, and these data were compared to similar measurements collected during the 2 months immediately following sign installation The risky behaviors encompassed a range of driver and pedestrian actions of varying severity, including motorists who initially crossed the plane of the gate but then reversed behind this line, pedestrians that crossed Timonium Road in front of the lowered gate, vehicles stopping beyond the plane of the gate arm or inside of the gate, and vehicles that began to move forward after the first train passed but then stopped.

Investigators found small reductions in unsafe behaviors though the total number of observations for each specific type of behavior was often very small. Overall, the frequency of risky behaviors decreased from 25.9 per 100 multiple train events before sign installation to 20.4 per 100 multiple train events in the first month after sign installation. This frequency decreased again to 16.7 per 100 multiple train events in the second month after installation, which may reflect increased driver awareness and comprehension through exposure, publicity, and word of mouth.

The apparent decrease in risky acts after sign installation may be somewhat misleading because it is based on the assumption that all risky behaviors are equally dangerous. In fact, an increase occurred in the number of drivers who crossed the gate line before realizing that a second train was coming and subsequently reversed to avoid the gate crashing on their vehicles. Though the number of observations of this incident type is too small to make a definitive judgment, it raises the possibility that the presence of an MTW may result in a dilemma situation for drivers who notice the MTW after beginning to cross the tracks. Though many factors may contribute to this phenomenon, the simplest countermeasures are to (1) improve the conspicuity of the MTW to ensure that the sign immediately draws the attention of motorists before they attempt to cross the tracks and (2) design phased displays in a way that the multiple train event and the need to remain stopped behind the gates are explicitly expressed in the first phase.

Summary: Multiple Train Warnings

Only two formal evaluations of MTW systems have been conducted, and both of these were limited in scope. Despite some notable safety improvements, the results of the demonstration projects in Los Angeles and Maryland indicate that the MTWs were less than optimal. For example, although more than 90 percent of pedestrians who viewed the Los Angeles sign in action interpreted that caution was necessary, only 4 percent specifically identified it as an MTW. Though comprehension might increase over time and with publicity campaigns, the initial lack of understanding is a significant concern. The feedback from pedestrians at this site indicated that the graphic signs conveyed the need for caution, but the specific reason for caution may be unclear. Investigators did not specifically assess road users comprehension of the Maryland MTA MTW. Maryland MTA selected the message to install by showing the three prototype messages to a group of MTA managers and having them complete a survey. Though the respondents' preference for the final sign was overwhelming, Maryland MTA did not survey the intended users of the sign (e.g., motor vehicle operators and pedestrians). Unlike MTA staff, roadway users would be naive to the purpose of the sign, and their impressions may have differed for that reason. After implementation, Maryland MTA conducted a mail survey to assess sign effectiveness. The sign received largely favorable impressions, but the survey did not assess sign comprehension. The before and after observations revealed some decrease in risky behaviors, but drivers still attempted to proceed across the tracks as the gates ascend, despite the active MTW. It is not clear whether drivers fail to see the sign, fail to comprehend the message, or simply choose to ignore the warning. In summary, the reduction in certain undesirable road user behaviors suggests the benefit of MTWs, but various user-centered concerns remain for optimal design.

3.3 Vehicle Control and Automated Enforcement

Vehicle control systems prevent collisions with trains by creating a physical barrier to prevent roadway users from entering the track area when a train is approaching. Typical stop arm gates provide a barrier, but drivers can often pass around these gates or even break through them, either unintentionally or intentionally. Although a number of novel and promising systems have been developed to reduce the ease and likelihood of thwarting gates, few can be described as ITS. Examples of such non-ITS systems include the StopGate™ Crashworthy Highway Railroad Intersection Barrier and four-quadrant gates.

Automated enforcement has been applied to a number of applications, including red light-running, speeding, and HRI applications. Automated enforcement is a controversial issue that often raises issues of privacy, constitutionality, and accuracy. Turner and Polk (1998) provide an overview of major issues in automated enforcement and how to go about establishing a successful automated enforcement program. Important aspects include informing the public of the effort, involving the judiciary, and passing enabling legislation. Additional concerns that must be addressed are citizens' concerns for privacy, concerns that the system is primarily for revenue generation, and the process and penalties associated with the citation process.

Automated enforcement has been implemented at a number of HRIs in the United States. These systems discourage drivers from driving around active crossing gates at HRIs and to deliver citations to violators. Although specific methods vary, these systems use sensors to determine when a rail crossing violation occurs and record images to support prosecution. Applied image capture technologies include both wet film 35mm requiring digitization with manual citation preparation and digital images with video transmitted to a local police department for citation generation. Some of the systems had sensors that were linked to the railroad circuitry while others were stand alone. The following provides brief descriptions of these systems.

3.3.1 Dragnet Vehicle Arresting Barrier (VAB) System—McLean, Illinois

Illinois DOT implemented the Dragnet VAB at three locations on the proposed Chicago-St. Louis high-speed corridor (Coleman & Venkataraman, 2001). The VABs essentially consisted of a net suspended above the roadway that can be lowered during train approach. When a vehicle strikes the net, it is quickly brought to a stop with minimal vehicular damage. The University of Illinois evaluated the systems. The evaluation period was 10 months, but, for a variety of reasons, including malfunctions and road construction, the system was operational for less than one-half of the days of the evaluation. VABs were installed at three HRIs, but sufficient data were only collected at one site: US-136 in McLean, which has average daily traffic of 2,800 vehicles per day and a speed limit of 45 mph. Two VABs were mounted at this site, one for each direction of traffic. VABs consisted of two towers, one on each side of the roadway. A net was suspended between the two towers perpendicular to the roadway. For eastbound traffic, the VAB was located 27.7 meters from the HRI stop gate. For westbound traffic, the VAB was located 46.2 meters from the stop gate. While no trains are approaching, the net is suspended over the roadway, above passing vehicles. System deployment occurs as follows (timings are approximate):

- *55 seconds before train arrival*: pairs of red lights on the VABs begin flashing
- *27 seconds before train arrival*: railroad lights and gates activate
- *13 seconds before train arrival*: VAB nets and railroad gates are fully deployed

Fixed signs upstream of the VABs instructed drivers to stop at the VAB when the red lights are flashing. Investigators found that 83 percent of drivers complied. All of the noncompliant drivers passed under the VAB before the railroad lights and gates activated. However, data indicated a trend over time where violations were becoming more frequent and more dangerous (closer to the point of train arrival), though interruptions to data collection prevented statistical confirmation of this trend. Unfortunately, this study did not make any comparisons to standard active grade crossings, though the increase in violations over time seems to indicate that the VAB did not have an ideal impact on driver behavior. Researchers cite a number of human factors problems with the system, including driver distraction caused by the large towers, the peripheral location of the flashing lights on the towers and cross bracing, and the fact that the VAB lights activate about 18 seconds before the railroad lights and gates activate. The Illinois DOT removed the VAB system after the evaluation period because frequent malfunctions made it unreliable and costly to maintain.

3.3.2 Automated Enforcement Demonstration Project—Jonesboro, Arizona

The first application of automated enforcement at an HRI was a joint venture of the city of Jonesboro and Burlington Northern & Santa Fe Railroad (BNSF) (Lammert, 1999). The site had a high rate of train-vehicle collisions and frequent damage to the gate arms caused by noncompliant motorists. An image capture system, which Science Applications International Corporation (SAIC) provided, used an infrared beam to detect violations, a camera to capture the violation, and telephone wire to transmit the data to police. No signs were used to inform drivers of the enforcement system. Officials estimate that an average of only two violations occurred per month with the enforcement system active and that the frequency of violations decreased during the first year of use. Investigators provided no data, however, on violation frequency before enforcement. Gate damage was also reported to be less frequent than it was before the enforcement phase. The system was in operation from 1991 to 1995, when it began to malfunction. It has remained offline ever since.

3.3.3 MBL Grade Crossing Safety Program—Los Angeles, California

LACMTA implemented an automated enforcement program on the MBL as part of a larger project intended to increase safety at HRIs on the MBL (Lammert, 1999). A number of problems, including HRI geometry and roadway user misunderstandings, contributed to a high rate of pedestrian and vehicle collisions with trains. In 1992, MTA responded by increasing police presence and ticketing at HRIs. Though successful, the program was too expensive to maintain. In the same year, MTA initiated a project to demonstrate the use of automated enforcement at two gated HRIs. Cameras were installed overlooking the HRIs. The cameras were not hidden, and nearby signs warned roadway users of their presence in English and Spanish. The signs had a small picture of two video cameras facing an MUTCD standard W-10 advance warning sign icon. The text messages below the icons were “PHOTO CITATIONS ISSUED” and “INFRACCIONES REGISTRADAS FOTOGRAFICAMENTE.” U.S. Public Technologies manufactured the camera systems. Photos generated by the system included a data overlay that included a timestamp and violation-specific data. Difficulties due to sun glare, missing license plates, and unmatched license plates resulted in citations being issued to only about one-half of recorded violators. Despite ticketing difficulties, gate-running violations decreased by 92 percent at one site and 68 percent at the other. Encouraged by this high rate of success, MTA added additional cameras at other HRIs along the MBL and reported a 70-percent reduction in trains colliding with vehicles at these HRIs.

3.3.4 Automated Enforcement at Highway-Rail Grade Crossings—Ames, Iowa

Officials in the city of Ames decided that an improvement was needed at one HRI that experienced an unusually high number of train-vehicle collisions. The officials decided to install an automated enforcement system (Lammert, 1999). Fixed signs were installed upstream of the HRI to inform motorists of the system. The message on the signs was “RR XING SURVEILLANCE SYSTEM” (Fitzpatrick, Bartoskewitz, & Carson, 1997). System designers chose to use the same SAIC system that was used in Jonesboro, Arizona. Two cameras were installed at the HRI; one facing each direction of traffic. Cold weather, however, interfered with the infrared detectors, which were subsequently replaced by loop detectors. Even with the detection upgrade, limitations still prevented citations from being issued. Photos taken at night, because of the brightness of the flash on the retro-reflective license plates often had unreadable license plate numbers.. Laws required violators to be personally identifiable, but the camera images rarely achieved this level of resolution. Citation notices were also required to be delivered in person, which substantially reduced the efficiency of the process. Because of these difficulties, the definition of a violation was scaled back to exclude the least egregious violators; rather than issuing punitive citations, officials chose to issue warnings instead.

3.3.5 Automated Railroad Crossing Enforcement System (ARCES)—DuPage County, Illinois

Beginning in 1999, the Illinois Commerce Commission conducted an evaluation of the effectiveness of ARCES at three HRIs in DuPage County (Illinois Commerce Commission, 2002). The HRIs chosen represent a cross-section of features, including a suburban downtown HRI, a four-lane urban HRI, and a two-lane rural HRI. A fourth site was added in 2002 but was not part of the initial investigation. Each location tested a slightly different type of photo enforcement system, including systems from ACS State and Local Solutions (formerly Lockheed Martin IMS), SAIC, Nestor Traffic Systems, and Proscan. Although questions regarding the legality of photo enforcement prevented sufficient data from being collected at one site, before-and-after comparisons showed gate violation reductions of 47 percent and 87 percent at the other two sites. Although collisions with trains were too rare at these sites to make a statistical comparison, the annual rate of collisions has been below average since ARCES implementation. The investigators conclude that automated enforcement is an effective means to reduce gate violations, but that the high cost of system installation, maintenance, and the citation process are likely to preclude broad implementation. If only implemented at high-risk HRIs that have a high number of violations, however, automated enforcement systems may generate sufficient revenue to recoup their cost within a few years of use.

Summary: Vehicle Control and Automated Enforcement

Results from field evaluations indicate that VABs, of the type described above, suffer from poor operational reliability and motorist noncompliance. On the other hand, automated enforcement can be an effective method to reduce the frequency of gate violations at HRIs. However, a number of issues, including privacy concerns and legal arguments, must be overcome before automated enforcement can be successful. Additionally, the system must be reliable and adequately maintained to ensure that violating vehicles can be identified. Previously implemented systems suffered from malfunctions. These problems were compounded in cases where no agency was clearly responsible for system maintenance and repair. Although none of the current systems appeared to cause detrimental behaviors among drivers (e.g., violating drivers becoming disoriented by a camera flash), implementers should consider the possibility of such effects. Another issue to consider is the extent of public outreach. Polk (n.d.) recommends a campaign to inform the public of the system's existence but not to publicize the exact locations. One possibility is to place camera housings at many HRIs and to rotate a small number of cameras between these sites. Finally, because of restrictive costs, it is important to choose sites for installation based on crash likelihood and frequency of violations.

3.4 Summary of Lessons Learned

Lessons learned from these deployments and demonstration projects suggest that advance alert and warning systems have the potential to provide safety and operational benefits, although technological and political challenges (i.e., DOT-Rail-community cooperation) often hamper, the development and successful implementation of these systems. Although most of the systems discussed in this chapter function at gated HRIs, they may also be applicable at passive HRIs where no active warning devices exist, in situations with reduced visibility, and at other high-risk locations. Nevertheless, no uniform system architecture or standardized set of messages has been adopted. Systems have varied in design and with regard to the types of information communicated to drivers, as well as the form in which the information is communicated to drivers. Two basic system distinctions have emerged: systems that provide additional information to drivers for the sake of better informed decisions (e.g., in-vehicle alerts and multiple train warnings) and systems that actively prevent or discourage undesirable behavior (e.g., vehicle control and automated enforcement). The majority of systems were implemented as demonstration projects and then removed soon after evaluation was complete. While some provided useful data on their effectiveness, others demonstrated the use of a new system without conducting any evaluation.

Table 1. Highway-rail intersection warnings and enforcement projects

System Name	Agency/Organization	Implementation	Description	Information Communicated
Information About Train Arrival				
Rail View	Texas DOT, Texas Transportation Institute	College Station, Texas	Provides real-time train movement information to emergency service providers, traffic management operators, and traffic signal controllers	• Train location • Train speed & direction • Estimated time of arrival at downstream HRIs • Duration that the train will occupy the HRI
Rail Monitor	Texas DOT, Texas Transportation Institute	Sugar Land, Texas	Provides HRI status information to police, fire, and EMS to allow responders to avoid unnecessary delays at train-occupied HRIs	• Train location • Train speed and direction • Train length • Estimated time of arrival and clearance at HRIs
Train Presence Information by HAR	Texas DOT, Texas Transportation Institute	Laredo, Texas	Uses HAR to broadcast automated messages and fixed flashing signs upstream of the HRI to warn drivers before they reach the HRI ("Train When Flashing," "Expect Delays")	• Intersection blocked • How long intersection has been blocked • Train direction

Table 1. Highway-rail intersection warnings and enforcement projects (continued)

System Name	Agency/Organization	Implementation	Description	Information Communicated
AWARD	Texas DOT, TransGuide, Part of the Metropolitan Model Deployment Initiative	San Antonio, Texas	Advises motorists and emergency responders of delays resulting from railroad blockages using changeable message signs posted near freeway exits	• Traffic delay due to train • Alternate route
IGC	New York State DOT, Alstom Signaling	New Hyde Park, New York	Uses train detection, vehicle detection, and communication equipment to improve roadway traffic flow, provide information to motorists, and enhance communications between train crews and the HRI	• Constant warning time • Emergency vehicle accommodation • Vehicle detection • Crossing status
In-Vehicle Signing System for School Buses at Railroad-Highway Grade Crossings	Minnesota DOT, 3M, Dynamic Vehicle Safety Systems	Glencoe, Minnesota	In-vehicle signing installed in 29 school buses; provides drivers with two types of information: (1) crossing alert and (2) train warning. Icons represent external RRX signs. Visual and audible alerts provide a minimum of 250 feet of warning time (equivalent to 6.8 seconds at 25 mph and 3.8 seconds at 45 mph)	• Crossing alert • Train warning

Table 1. Highway-rail intersection warnings and enforcement projects (continued)

System Name	Agency/Organization	Implementation	Description	Information Communicated
Integrated Train Detection and Traffic Control System	Minnesota DOT, Minnesota Guidestar, SRF Consulting	Moorhead, Minnesota	Three-phased project. No communication to motorists at this time, only system development and testing. Future plans include using CMSs and linked database to provide emergency vehicle dispatchers with train data	Future: • (CMS) Number of minutes nearest HRI will be blocked • Train estimated time of arrival at each HRI
Advisory On-Board Warning	Illinois DOT, University of Illinois at Urbana-Champaign, Raytheon Systems	Metra-Milwaukee North Line	A pilot study with a 9-month operational phase involving more than 270 equipped vehicles. System provides in-vehicle warnings (text/audio) that a train is approaching or at the HRI. Uses two different system messages: caution and warning	• Caution or warning (indicates train approaching or at HRI)
Multiple Train Warnings				
Pedestrian Second Train Warning	LACMTA	Los Angeles, California	Warns pedestrians that trains are approaching on more than one track at a pedestrian crossing area	• Multiple trains arriving at HRI
Second Train Warning Sign	Maryland MTA	Timonium, Maryland	Warns motorists at a gated LRT HRI that trains are approaching on both tracks	• Multiple trains arriving at HRI

Table 1. Highway-rail intersection warnings and enforcement projects (continued)

System Name	Agency/Organization	Implementation	Description	Information Communicated
Vehicle Control and Automated Enforcement				
Dragnet VAB	Illinois DOT, University of Illinois	McLean, Illinois	Physically stop intruding vehicles by using nets	• Warning (indicates train approaching or at HRI)
Automated Enforcement Demonstration Project	City of Jonesboro, BNSF	Jonesboro, Arkansas	Detection and image capture system designed to automatically photograph and cite drivers who cross tracks while gates are down	• Citations mailed to owners of violating vehicles
MBL Grade Crossing Safety Program	LACMTA	Los Angeles, CA	Detection and image capture system designed to automatically photograph and cite drivers who cross tracks while gates are down	• Citations mailed to owners of violating vehicles
Automated Enforcement at Highway-Rail Grade Crossings		Ames, Iowa	Detection and image capture system designed to automatically photograph and cite drivers who cross tracks while gates are down. System used same hardware as Jonesboro application	• Nonpunitive warnings hand delivered to violators at home
ARCES	Illinois Commerce Commission	DuPage, Illinois	Detection and image capture system designed to automatically photograph and cite drivers who cross tracks while gates are down	• Citations mailed to owners of violating vehicles

Part III: General Human Factors Considerations for Application of ITS to HRIs

4. Message Factors

4.1 Background

This chapter deals with the general attributes of ITS messages related to the HRI. The purpose of ITS messages presented to a road user is to bring about some desired behavior in the road user. This chapter will identify attributes of messages that promote appropriate behavior for the range of intended users. The chapter deals with general message attributes, such as information content, format, and timing, rather than details of the display itself. It also encompasses system considerations (i.e., general concerns for ITS HRI messages as elements of the broader contexts in which road users encounter them).

This chapter is closely related to Chapter 5, Roadside Displays; Chapter 6, In-Vehicle Displays; and Chapter 7, Displays for Pedestrians. To some extent, different considerations and different available options for roadside messages and in-vehicle messages exist. Therefore, these subsequent chapters deal in greater detail with a number of message factors. In Chapter 4, the concern is with the broader attributes of messages that are relevant to both roadside and in-vehicle displays. Many recommendations, however, are closely related to recommendations given in other chapters. Cross references are given in the text.

Getting the human user to respond appropriately to warnings and alerts has been an issue in many different domains of activity, including workplace safety, consumer product use, medical device use, control rooms, and aviation. Road user behavior is not unique in this regard. It is often difficult to get people to notice warning information, even when it is plainly visible, and difficult to get them to respond as desired, even when the message is noticed. Research and experience across these many applications, as well as work specifically on TCDs or ITS, has pointed to some of the attributes that an effective message should possess. For example, research and guidance on ITS messages exists for advanced traveler information systems (Campbell, Carney, & Kantowitz, 1998), driver route guidance (Lerner & Llaneras, 2000), and in-vehicle information systems (Driver Focus-Telematics Working Group, 2003). Research and guidance on TCD messages includes warning signs (Lunenfeld & Alexander, 1990) and variable message displays (Dudek, 2003). Examples of research and guidance from other domains include consumer product instructions and warnings (Singer, Balliro, & Lerner, 2003), advanced traffic management centers (Sobhi & Kelly, 1999), and nuclear power plant control rooms (O'Hara, Higgins, Persensky, Lewis, & Bongarra, 2004). Broad reviews and integrations of the range of literature on warning effectiveness have occurred (e.g., Miller, Lehto, & Frantz, 2001). The discussion and recommendations in this chapter make use of the broader literature on warnings, as well as specific information in highway safety and ITS literature.

4.2 Key Human Factors Issues and Need for Guidance

4.2.1 Issue: Distinguishing Different Types of Messages

Many different types of information may relate to the presence or status of HRIs. Some messages concern safety issues while others concern non-safety issues, such as travel information and route selection. A particular ITS display device—such as a CMS or an in-vehicle information interface—may display safety and non-safety messages at various times and may not be dedicated specifically to HRI information. Some messages may be urgent and require immediate driver response while others can be processed more leisurely or even safely ignored. Safety-critical messages must be immediately distinguishable from other messages and must have attributes that ensure they are responded to quickly and reliably.

Traditional fixed roadway signing has various color and shape conventions so that motorists can immediately recognize the category of information being communicated. The effectiveness of this coding—whether most motorists actually understand and respond to the code as well as might be desired—is somewhat questionable, but it is seen as a critical aspect of the sign and marking system. The MUTCD (Federal Highway Administration, 2003) in Section 1A.12 defines the general meaning of reserved colors (e.g., with background sign colors of yellow indicating warning, white indicating regulation, and green indicating direction guidance). Active TCDs also have conventions (e.g., red flashing lights for stop messages on intersection traffic signals and at HRIs). No convention exists for ITS applications related to HRIs to make various message types distinguishable. For CMSs, there is typically no use of color, shape, or other coding occurs, even though current technologies permit this (Lerner, Singer, & Huey, 2004). For in-vehicle systems, no accepted convention exists.

4.2.2 Issue: Requirements for Effective Warning Messages

Warnings are the most critical type of message. As this term is used here, a warning is a time-critical message that informs the road user of a hazard or required action of which he/she may be unaware. A substantial human factors literature exists on warning effectiveness across a range of domains (transportation safety, product warnings, workplace warnings, instructional materials, control rooms, and medical devices). This literature has identified a number of necessary stages that must be successfully met if a warning is to be effective. The following lists these general stages:

- Notice the display
- Comprehend the message
- Accept the validity of the message (credibility)
- Comply with the message

Noticing has to do with the conspicuity and salience of the display. This is primarily related to display features rather than message features. Conspicuity is dealt with only generally in this chapter and more specifically in Chapter 5 for roadside displays and Chapter 6 for in-vehicle displays. Comprehension includes such concerns as the legibility or audibility of the message, standardization of message components, and the user's mental model of the system. Message credibility can be a particular concern for real-time ITS displays. It is related to factors such as accuracy, timeliness, nuisance warnings, consistency with expectancies, and the perceived motives of the message provider. Compliance is important to focus on because even when messages are understood and perceived as credible, they may not be complied with. Noncompliance may be intentional on the road user's part because of the desire to save time, following the example of other road users, or other motivations. Noncompliance may also be unintentional, if the road user is not capable of responding in time or with accuracy. This relates to factors of message timing, workload, consistency of operation, and risk perception. For traditional TCDs (in general and for HRI devices in particular), standards and practice have already helped establish the conspicuity, comprehensibility, and credibility of the message, although perhaps not always optimally. For example, drivers do not always understand what to do at a signalized HRI, and many are skeptical of the timing of signals and gates (e.g., Lerner, Ratte, & Walker, 1989). For innovative ITS HRI applications, road users do not bring a history of familiarity with the device, and guidance for system developers is limited.

4.2.3 Issue: Unintended Consequences

ITS information can have unintended consequences that are problematic. For example, a display might draw attention away from other important driving cues or add to the driver's mental workload. Messages can be intrusive or annoying, leading to poor acceptance or defeat of the system. Research has found that nuisance speech messages are more annoying to drivers than tonal signals (Lerner, Dekker, Steinberg, & Huey, 1996). Road users might also use ITS information in ways unintended by the designer. For example, information about train arrival time might lead some drivers to speed to beat the train, or information about a delay at an HRI could lead to illegal or inappropriate lane changes or U-turns. Another potential unintended consequence is automation complacency (e.g., Endsley, 1996). This is a general phenomenon seen in systems where part of the operator's task is automated. Vigilance and situation awareness may be reduced, and the user may just assume that system status is proper. Applied to the HRI situation, an example might be drivers that fail to search at a passive crossing because they expect to get an alert from a train-based warning system. Related to automation complacency is the phenomenon that has been termed *risk compensation* or *behavior feedback* (e.g., Evans, 1991). Various analyses of highway safety improvements have shown that the improvement does not simply overlay some benefit on current driver behavior. Rather, the new feature leads to a change in driver behavior, which can reduce or even eliminate the potential benefit. Rather than passively accepting the improvement as simply a safety enhancement, drivers may trade off all or part of the safety benefit for some other perceived benefit. A classic example is a Swedish study (Rumar et al., 1976) that found that drivers equipped with studded tires drove at higher speeds than other traffic on icy roads, giving back a portion of the safety benefit for the convenience of faster travel. ITS applications for HRIs might result in similar effects. For example, if drivers anticipate receiving in-vehicle alerts from train-based systems, they may approach HRIs at higher speeds. While the possible effects of HRI ITS treatments may be speculative, the various unintended consequences of ITS messages are well established as possibilities to which the designer must be alert.

4.2.4 Issue: Message Design for Specific Roadway Users

ITS messages should consider the needs of specific road users. Two general aspects to this exist. One is to take advantage of ITS capabilities so that the message can be optimized for a particular individual motorist and vehicle receiving the message. The other is to ensure that the message is appropriate for particular groups within the broader population of road users.

Fixed highway signs, signals, and markings provide the same message all the time, without regard to the user, the vehicle, and current traffic and environmental conditions. As a consequence, features of the message (content, location, timing, appearance) must be designed based on certain assumptions, which may not always be appropriate. The criteria are often based on a conservative (less capable) design driver (e.g., 85th percentile on some attribute), which makes the assumptions too conservative for the majority of drivers and yet may still fail to adequately address the more extreme drivers. This mismatch can weaken the message. ITS capabilities offer the possibility of recognizing specific aspects of the situation and tailoring the message for the road user. For example, the timing or content of a message about an HRI ahead might be modified based on the vehicle's speed, vehicle size and braking capability, roadway surface conditions, visibility conditions, whether there is a queue of traffic, or individual driver attributes, such as reaction time or local familiarity.

Among the population groups that must be considered in the design of ITS messages are the non-English-literate and older people. Although various current in-vehicle products may offer a language option for the display, providing a menu of language options is not possible for roadway-based signs (although sometimes a message may be presented in two languages, as in Section 3.3.3). Unlike much fixed signage, which uses graphical elements such as icons, shapes, and colors, current roadway signs for ITS messaging generally use text messages on CMS displays. Therefore the non-English-literate may not receive useful information. For older road users, important considerations include poorer vision, slower information processing, and longer perception-reaction times. Various studies have also shown age differences in how drivers comprehend the meaning of different signs and symbols. Older drivers will comprise an increasingly greater portion of the driving population as the baby boom generation ages, and messages must be usable by this group. Another segment of the population that must be considered for pedestrian-related displays is those with disabilities. Mobility characteristics (e.g., wheel chair use) may influence the optimal timing or content of messages for pedestrians. Sensory impairments (visual or auditory) also influence message criteria. The *Americans with Disabilities Act (ADA) Accessibility Guidelines for Buildings and Facilities* (1998) is specifically referenced in the MUTCD (Federal Highway Administration, 2003), and ADA requirements are a general issue for roadway design, operations, and displays. Persons with disabilities likewise should be considered in the design of ITS messages intended for pedestrians. Chapter 7, Displays for Pedestrians, deals further with some of these concerns.

4.2.5 Issue: Modes of Display

One issue facing the designer of ITS displays is the choice of mode(s) in which to present the message. The predominant mode today is visual, in either text or pictorial/symbolic form. Acoustic messages are increasingly common for in-vehicle ITS applications and may be in the form of speech or non-speech signals (*earcons*). Acoustic signals are integral parts of the traditional (non-ITS) HRI system through bells at active crossings and train horns. Haptic and tactile signals can be used in vehicles for alerting; examples include vibration of the steering wheel or pedals, or counterforces in the steering wheel or accelerator pedal. Haptic and tactile signals are present on the roadway in the form of rumble strips and raised pavement markers but only as fixed roadway features and not as controllable ITS messages. The choice of mode may be quite application-specific and will have different considerations for in-vehicle and roadway-based devices. Therefore further discussion will primarily be in other chapters (Chapters 5, 6, 7). Some general human factors considerations related to the mode of display, however, are appropriately considered for any application.

4.2.6 Issue: System Considerations

In designing ITS displays for HRI applications, it is essential to approach the problem from a systems perspective. The message about the HRI is presented to the roadway user in a complex, real-world context. Although the designer of the application may be specifically focused on some HRI information, the roadway user who receives that information is not so narrowly focused. Drivers must attend to the full array of information presented to them while dealing with vehicle control and traffic events, and the ITS information about the HRI is but one element in this array. Therefore, if the ITS application is to be successful, it must communicate effectively within the information environment in which the road user operates.

Various system contexts exist in which ITS messages about the HRI must operate. These contexts include those listed below.

- *ITS services context.* ITS information and services that are present in addition to the specific HRI message of interest. For example, an in-vehicle system might provide information related to other ITS user services, such as en-route driver information, route guidance, traveler services information, and collision avoidance. Messages related to HRI information must function effectively within this broader ITS system.
- *Roadway information system.* The road user is confronted with information from traffic control devices of all sorts, including signs, signals, and markings. Information from less formal sources also exist, such as the surrounding environment, tree lines, and road geometry. This information system includes information that may be related to the ITS information about the HRI, as well as information about unrelated aspects of the road. All of this information must function in a mutually compatible way. The content, timing, location, appearance, and density of the various information sources must work in a complementary manner and not generate confusion or unreasonable demands on the road user.
- *Traffic operations environment.* The ITS message about the HRI will occur while the driver is coping with all of the other things a motorist must contend with, such as navigating, dealing with other traffic, selecting the proper path and speed, and monitoring the entire situation for possible hazards. The ITS message will have to function effectively within this context and should not lead to driver problems in dealing with other critical aspects of the driving task at that time.
- *Roadway and railway network.* The road user encounters an ITS application at a particular HRI within the context of a network of roads and HRIs. The road user's experience with the network will influence expectancies and behaviors at particular sites. For example, the characteristics of the network will influence whether the drivers expect to encounter an HRI, whether they anticipate an active or passive crossing, and whether they expect high-speed trains. The use of ITS within this system may influence the response to an ITS message at any one location. For example, if an ITS system that transmits an in-vehicle warning about arriving trains is operational at some HRI in a region but not others, drivers may have an inaccurate expectation about whether they will receive a warning; or if installations at different HRIs have different operational features (e.g., different algorithms for when to initiate a message), the road user's mental model of what the TCD does may be inaccurate.

The ITS HRI application is only one component of each of these systems. Good human factors design must include consideration of how the specific application functions within these systems because the roadway user encounters the application within these more general contexts. Numerous aspects to these system considerations exist, including the following:

- *Uniformity and compatibility of messages and display features from application to application.*
- *Integration of ITS functions.* Prototype applications involving ITS at the HRI typically have been developed and evaluated as stand-alone devices or services. As ITS services proliferate, however, individual applications will not perform optimally if they are not systematically integrated with other ITS information. This is particularly a concern for in-vehicle systems.
- *Management of driver workload.* Drivers must simultaneously deal with various aspects of the driving task (e.g., maneuvering, watching for hazards, speed monitoring, lane keeping, navigating) and with various sources of information (signs, markings, traffic, roadside, in-vehicle sources). When the demand on the driver is excessive, information gets missed and driving performance deteriorates. Therefore ITS messages about the HRI must be considered in terms of how they contribute to driver workload as well as in terms of how they will function in the context of the pre-existing driver workload.
- *Development of road user expectancies about a given situation based on his/her experience with the entire system.* For example, if an ITS warning system is installed at some HRIs in an area, a road user might incorrectly anticipate that the system is operational at all HRIs in the area.
- *Compatibility of ITS HRI messages with the roadway traffic control system.*

4.3 Recommendations

Recommendations for message factors are grouped under nine topics, in the box provided on the next page. For each topic, the individual recommendation statements are given.

4.3.1 Factors to Ensure Message is Noticed

Recommendation 4-1: Ensure adequate conspicuity of the message

Locate visual displays near the road user's probable line of site, within 20 degrees if possible. Consider message modes (acoustic, tactile) or alerting cues that do not require the driver to be oriented toward the message. For visual displays, conspicuity can be enhanced by size, contrast, color, and movement (flashing, animation). Conspicuity enhancements must be considered along with potential negative consequences, such as driver distraction, annoyance, intrusiveness, esthetics, and interference and incompatibility with other roadway communication elements. Specific recommendations for conspicuity depend on the particular ITS application.

[Also see: Sections 5.2.2, 8.2.4, 11.2.1 and Recommendations 5-3 through 5-9, 6-6, 6-8 through 6-13, 7-1, 7-4, 8-10, 11-6]

Table 2. List of recommendations for message factors

Factors to ensure message is noticed

1. Ensure adequate conspicuity of the message.
2. Limit displays to needed messages.

Factors to improve comprehension of message

3. Ensure legibility and audibility under probable operating conditions.
4. Make the desired road user action explicit and unambiguous.
5. Use standard or common wording, abbreviations, images, and formats.
6. Test for road user comprehension.
7. Promote compatibility with the road user's mental model of how the system works.

Factors to improve credibility of message

8. Ensure that information is accurate and timely.
9. Minimize the frequency of all categories of nonuseful alerts.
10. Consider road user perceptions about motivations and criteria of traffic-rail authorities.

Factors to improve compliance with the message

11. Provide adequate response time, consistent operation, and controlled workload.
12. Avoid excessively conservative criteria.
13. Provide road user feedback regarding noncompliance and unsafe behaviors.

Distinguishing safety-critical messages

14. Design safety-critical messages to be immediately recognizable as urgent safety alerts and discriminable from other messages.

Choice of message display mode

15. Consider the advantages and disadvantages of alternative display modes.

Unintended consequences of the message

16. Avoid driver distraction.
17. Consider the potential effects of automation complacency and risk compensation (behavioral adaptation).
18. Minimize annoyance.
19. Anticipate road user misuse of information.

Message appropriateness for specific road users

20. Customize ITS messages for the current situation.
21. Devise messages for effective communication with non-English-literate road users.
22. Devise messages for effective communication with older road users.
23. Devise messages for effective communication with road users having disabilities.

System considerations

24. Provide uniform messages and displays across information sources and sites.
25. Provide compatible message timing among information sources.
26. Manage information demand and driver workload.
27. Integrate ITS functions.
28. Avoid the development of inappropriate road user expectancies about the roadway and railway network.
29. Integrate ITS HRI displays and controls with the roadway traffic control system.

Rationale

The road user cannot receive a message unless he/she is aware of the presence of the message display. The message must be conspicuous enough that it is detected by the road user in a reliable and timely way. This is especially so for time-critical warning messages. Therefore, the physical aspects of the message display must make the display stand out to the driver when and where the information is needed. Because visual messages depend on the road user's eyes being oriented toward the display, conspicuity is enhanced if the visual display can be located near where the gaze is likely to be directed and if the display includes those factors that increase conspicuity, particularly if the display is initially outside of foveal (central) view. Some conspicuity enhancements, however, may lead to distraction or annoyance and so should be used only with caution [Also see: Recommendations 4-17, 4-18]. For example, animated CMS displays can be very attention-getting yet raise real questions about appropriateness (Lerner et al., 2004), and the MUTCD (Federal Highway Administration, 2003) includes prohibitions against the use of animation for certain applications. Acoustic signals have the advantage of remaining detectable wherever the road user's gaze is directed. This is also true for tactile signals although they have been used minimally to date. Brief acoustic signals can help to alert the driver to the presence of a visual message, or the message itself may be in acoustic (speech or non-speech) mode. When messages are not useful to the road user (false alarms, overly conservative, information is already known), however, acoustic signals (and especially speech messages) may be more annoying and less acceptable to users.

While the general principle of conspicuity in this guideline is common to all ITS displays for the HRI, the specific means of meeting conspicuity needs will depend on whether the ITS display is within the vehicle, on the road and intended for motorized traffic, or on the road and intended for pedestrians.

Recommendation 4-2: Limit displays to needed messages

Warnings, alerts, and other messages not directly requested by the road user should be limited in number and should meet a specific user need. Ideally, the ITS display will remain dark (for visual) or silent (for acoustic) when no need is present. This recommendation applies to messages that are intended to alert the road user, in contrast to information about conditions that the road user is actively seeking. For example, a route guidance display is appropriately maintained as long as the driver seeks to use it.

Rationale

It is easier to detect the presence versus absence of a display rather than a change from one display to another. Therefore the attention-getting value of a particular message about the HRI will be enhanced if the display field (sign panel, in-vehicle display, and acoustic and speech communications) is only active when messages are required. Furthermore, the frequent presentation of messages can reduce the salience of the existence of a message. This problem of overuse is a general concern for highway safety messages of any type. For example, the MUTCD (FHWA, 2003) in Section 2A.04, Excessive Use of Signs, states that regulatory and warning signs "should be used conservatively because these signs, if used in excess, tend to lose their effectiveness."

One caveat to this recommendation concerns failure modes, particularly for warning systems. Existing active HRI warning systems maintain a standby power system and can operate in warning mode when a power failure or other system failure occurs. If a warning system fails, the system should be able to operate in a failure mode in which the warning message is displayed for the duration of the failure, even though the system may be incapable of detecting threats.

4.3.2 Factors to Improve Comprehension of Message

Recommendation 4-3: Ensure legibility and audibility under probable operating conditions

Rationale

Even if the driver notices the display, the display can only communicate a message if it is legible (visual messages) or audible (acoustic non-speech and speech messages). While this is evident, the important point in this recommendation is to determine the likely range of real-world operating conditions. For roadway visual displays, this includes weather-related visibility conditions, such as rain, snow, fog, and spray; lighting-related concerns, such as veiling glare, disability glare from oncoming traffic, poor illumination or retro reflectance at night; and obscuration by objects, such as truck traffic or vegetation. In-vehicle displays may also suffer glare, and acoustic displays may be degraded by engine noise, wind, conversation, and entertainment systems. Specific criteria for legible or audible messages are distinct for roadway displays and in-vehicle displays. Therefore Chapters 5 and 6 provide more specific recommendations.

Recommendation 4-4: Make the desired road user action explicit and unambiguous

While it is important to convey the nature of the hazard or other specific information about the situation, this information alone may not be adequate to ensure a proper and timely response. Part of the message conveyed to the road user should be a clear sense of what action to take. This does not necessarily have to be stated explicitly, but if it is implied, confirm that the road users make the proper inferences.

Rationale

Road users may understand the general nature of a message, but this does not mean that they fully comprehend the appropriate action they should take in response to that information. Examples of this may be seen in current fixed HRI signing. For example, the Number of Tracks Sign (R15-2) may fully convey the message that there are a certain number of tracks at that HRI, but road users may have no idea why this is useful information and how it should affect their actions. Similar lack of full understanding might occur with ITS messages. For example, if an in-vehicle system provides an indication that there is an HRI ahead, the road user may not know if this means he/she should slow down immediately or take some other action. If an HRI employs an advance barrier system, the road user may not understand where to stop. Although making the user response unambiguous is desirable for any sign, this is a particular concern for HRI ITS messages because the applications are unfamiliar and not standardized, so the road user does not have previous experience.

Recommendation 4-5: Use standard or common wording, abbreviations, images, and formats

Display elements should be familiar to the road user and have their understandability established. Sharing common elements also contributes to display uniformity throughout the information system [Also see: Recommendation 4-24]. Ideally, key aspects of the message wording and other display elements should be standardized. In the absence of consensus practices, where possible, use established conventions from related applications.

Rationale

Displays for roadway and in-vehicle ITS applications do not have the advantage of established practices or standards for the content of the display. Developers of prototype or demonstration systems may use different words or images for the same concept. Designers should take advantage of previous research and other applications for determining the components of their messages. For example, abbreviations[2] used for CMS are based on research, and their subsequent use in various applications promotes comprehension when used for the HRI application. Furthermore, if new displays are developed without regard to common usage, this results in a lack of uniformity throughout the information system. Recommendation 4-24 discusses the need for uniformity further. Wording, icons, and other display elements can be adapted from fixed roadway signs that are already familiar to road users. Chapter 5 discusses some proposed ITS messages and sets of abbreviations which the designer should consider. In the absence of consensus practices, designers should take advantage of existing conventions and resources where possible and use message elements with which road users are likely to be familiar.

Recommendation 4-6: Test for road user comprehension

For novel displays, confirm that the intended message is fully conveyed to the range of intended users. This is particularly necessary for pictorial, diagrammatic, or symbolic displays, but misunderstanding can still occur even with text or speech messages. Comprehension tests should include a representative range of road users, including older people.

Rationale

In the area of TCDs, many examples of signs, signals, and markings exist that are poorly comprehended, even after many years of use (Knoblauch & Pietrucha, 1985). This includes signs associated with the HRI in particular (Lerner et al., 1989). Road user experience and public education are unlikely to overcome poor communication. It is important to confirm that a new display actually conveys the intended message. Comprehension testing has been lacking in various ITS applications. Many ITS implementations reviewed in this project did not include adequate comprehension testing before activation. Many displays were chosen by the designer or an internal committee that is not representative of the range of road users. While it may be evident that road users may misinterpret icons, symbols, color codes, or other nonlinguistic elements, even word messages may not convey the meaning intended by the designer (Dewar & Olson, 2001).

Although comprehension testing may sound straightforward, a number of complexities and issues actually exist. Various techniques exist, none of which is routinely accepted, and there is no consensus criterion for acceptability. Findings may be influenced by the context in which the displays are presented, and by whether multiple choice, short answer, or behavioral methods are used to measure comprehension. Images can be displayed with various degrees of sophistication,

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[2] A reviewer who teaches message creation for CMSs emphasized that before using an abbreviation, developers should try to find a simpler way to say the same thing without abbreviating.

from dynamic display in a simulator setting to paper images. Comprehension testing methods must, therefore, be carefully thought out so that the findings are meaningful for the particular application.

However the testing is done, it is important to look not only at the frequency of correct understanding but also at the nature of misunderstandings. Misunderstandings may provide clues as to how to improve the display. Additionally, certain misunderstandings, termed *critical confusions*, may be very dangerous since the viewer interprets the message in a manner that might lead to an inappropriate action. For example, if a display at an HRI showed the remaining time until a train clears the HRI, but a road user interpreted this as showing the time until a train arrives at an HRI, a driver might believe an opportunity to cross exists when in fact there is none. When testing comprehension, it is important to use a test population that is generally representative of road users. Convenience samples drawn from the system developer's staff or clients may bring different levels of sophistication about displays, HRIs, and safety problems. In addition, certain population groups may have different levels of comprehension. In particular, many studies have found poorer comprehension of signs and symbols among older drivers.

Recommendation 4-7: Promote compatibility with the road user's mental model of how the system works

Inappropriate behaviors may occur when the road user's conception of how the information or warning system operates conflicts with the actual manner of operation. Ideally, the system developers should understand the road user's perspective and design the system to be compatible with it. Otherwise, some remedial action may be required. Focus groups or indepth interviews of road users may be very helpful for addressing this, in both the design stage and after implementation. Simple survey questionnaires or limited testing of message comprehension may not be adequate to uncover subtle but possibly important misconceptions in the road user's mental model of the system [Also see: Recommendation 4-28].

Rationale

The user of an ITS system will have some conception of how the system works, what information it provides, how it responds, how accurate it is, the conditions under which it works, and so forth. This mental model of the system may or may not be accurate. Where the road user has an inaccurate mental model, a potential for acting inappropriately based on a misconception exists. For example, consider a train-based system that transmits a signal to activate in-vehicle or roadside messages at a passive HRI. If this system only activates in response to higher speed trains, road users may not realize this; in their mental model, the system will activate in response to all trains. Therefore, they may fail to engage in proper search at the HRI; or road users may believe the system is implemented at all HRIs in a corridor, whereas in fact it may only be installed at problem HRIs. System designers, engineers, and other rail or highway authorities may bring very different knowledge and experience to the situation, in contrast to typical road users. Things that may appear obvious to them may not be recognized by many road users. In devising message systems for the HRI, it is essential to try to think like a road user. It may be very helpful to conduct focus groups or interviews with road users to get insights into their interpretation of how the system works. To uncover these user perceptions, however, there must be an opportunity to probe for subtle misconceptions and to give the respondents opportunities to raise issues that the designer may not have considered. For this reason, simple survey questions may not be very revealing. The issue also goes beyond simply determining whether the road user understands a display. For instance, in the example above, a driver may understand the meaning of the train approaching display perfectly well, yet have an important misunderstanding of how the warning system is implemented.

4.3.3 Factors to Improve Credibility of Message

Recommendation 4-8: Ensure that information is accurate and timely

The perceived credibility of ITS information and road user satisfaction with ITS systems are sensitive to the accuracy of the information. Information may be inaccurate due to limited data, infrequent updates, the accuracy of predictive algorithms, or system failure modes.

Rationale

ITS systems lose credibility if the information provided is inaccurate or outdated (Campbell et al., 1998; Lerner & Llaneras, 2000). Sometimes the system designer is faced with the trade-off between providing the road user with more and better information versus introducing the possibility of inaccurate information. For example, an ITS system may inform a driver about the probable delay at the HRI and propose an alternate route. While this is useful information, the accuracy of the prediction about a time delay depends on the estimation of train arrival time and traffic conditions. The farther in advance the information is provided (allowing drivers to select alternate routes), the more the prediction is subject to error. Road users will tolerate some inaccuracy in the system. Research (e.g., Kantowitz, Hanowski, & Kantowitz, 1997) has found that, while relatively small levels of inaccuracy have a deleterious effect on driver trust and satisfaction with the system, effects on actual compliance with the information are not substantial until a greater degree of inaccuracy occurs.

Guidelines produced for traffic routing information (Lerner & Llaneras, 2000) include the following recommendations: update information frequently and time-stamp traffic information; supplement current information with predictive information; and be conservative and accept some delay in providing information to avoid disseminating erroneous information.

Recommendation 4-9: Minimize the frequency of all categories of nonuseful alerts

Warning messages lose their credibility when they occur frequently. Any warning that is not perceived as relevant by the road user can damage credibility. Consider the following types of nonuseful warning messages:

- Warnings triggered by inappropriate stimuli
- Warnings triggered by inaccurate and unreliable information
- Warnings initiated because the system cannot discriminate among threatening and non-threatening scenarios (e.g., stationary versus moving trains)
- Warnings that are redundant because the road user is already aware of the situation
- Warnings that occur too early to be relevant
- Warnings that occur too late to be helpful
- Warnings not relevant for this particular road user [Also see: Recommendation 4-23]

Non-useful messages can have negative effects on credibility for the particular HRI application, as well as for the ITS system of which the application may be a part.

Rationale

Research has shown that inappropriate messages not only reduce the perceived credibility (or trust) of an automated system (e.g., Parasuraman, 1997), but that nonuseful alerts also result in slower and less reliable responding to the signal (e.g., Chugh & Caird, 1999) and greater user annoyance with the system (e.g., Lerner et al., 1996). While nearly all design guides provide a recommendation to limit nuisance warnings, it is very difficult to quantify this requirement, and tolerable limits are no doubt quite situation-specific. Any warning that is not useful to the road user can damage the credibility of the warning system, but no research compares the effects of the various categories of non-useful warnings. For example, it may be the case that an alarm triggered by an inappropriate, but visible, stimulus is less damaging to credibility than an alarm that is generated by no apparent event. Similarly, little is known about the acceptability of non-useful alarm rates for an application that is part of a larger system. For example, if a train warning function is part of a larger in-vehicle ITS warning system, how is the credibility of the HRI-related warning affected by nuisance alarm rates for other applications in the system (e.g., rear-end collision warnings)? While data are lacking, it would be reasonable to assume that the overall performance of the system influences the user of an ITS system in any individual application.

Recommendation 4-10: Consider road user perceptions about the motivations and criteria of traffic-rail authorities

Rationale

Road users will consider a message credible to the extent they perceive it is intended for their benefit. They may question the intent of the authorities who operate an ITS service. Possible examples include the following:

- Alternative route recommendations are based on consideration of neighborhood residents or to optimize the performance of an entire roadway system, rather than to optimize the trip of the particular road user
- Cautionary messages are there to protect the operational authorities from liability but are not really necessary
- Messages are intended for other road users (less familiar, less skillful) but not for more competent users
- Regulatory controls or automated enforcement are there for revenue-generating purposes and are not really safety relevant

Perceptions such as these, whether accurate or not, can result in the road user rejecting the message as irrelevant. To the extent possible, the perceived personal benefits of compliance should be made as evident as possible. It may be difficult to do this within the constraints of a traffic control device display. Therefore, the perceived relevance of the system may need to be addressed through public education or enforcement activities.

4.3.4 Factors to Improve Compliance with the Message

Recommendation 4-11: Provide adequate response time, consistent operation, and controlled workload

Rationale

Even if road users comprehend and accept the credibility of an ITS message, they may fail to comply with the message due to the difficulty of performing the correct action. Factors that cause difficulty include the following:

- Unclear what the proper response is, multiple response options
- Insufficient time to execute the desired response
- Inconsistency in operational aspects (e.g., message location, timing)
- Competing demands (high driver workload)

Response time and distance requirements for driving situations are frequently based on the concepts of driver perception-reaction time (PRT) and maneuver time or distance (AASHTO, 2001). The conceptual model is a sequential one, where the PRT process generates a selected driving maneuver that then begins at the completion of the PRT period. Highway design equations use PRT and maneuver time and distance to determine sight distance requirements. PRT is the time it takes for a driver to recognize a situation, determine the driving response, and initiate the maneuver. This mental process may feel nearly instantaneous to the driver but is frequently (depending on the situation) on the order of seconds. For example, 2.5 seconds is the PRT used for stopping distance requirements, and, at highway speeds, the distance traveled while making a decision can be hundreds of feet. Driver PRT is related to the simplicity of the response and the number of alternatives (AASHTO, 2001; Pline, 2001).

Inconsistency in operational aspects affects the road user's ability to comply through its effect on driver expectancy. Road users will have some expectancy about probable messages and message formats, such as where the message should be located, how it is timed, how much time they have to respond, and so forth. If these characteristics vary from system to system or site to site, road users may have inaccurate expectancies. When road users' expectancies are violated, their responses may be slow and error prone.

Driver workload is a result of a variety of factors beyond the ITS HRI message itself. Recommendation 4-16 addresses workload aspects of the HRI message. But workload is also related to other driving and non-driving tasks that a motorist may be engaged in. Many non-driving activities (e.g., cell phone use, entertainment system use) may be beyond the control of the ITS system operator or traffic engineer. Other aspects of the roadway or roadside or vehicle, however, are either predictable or controllable and should be considered when evaluating driver workload. ITS HRI display location should not conflict with high demand situations. These include roadway geometric features (e.g., curves, intersections, lane drops), traffic interactions (e.g., merges, driveways, lane changing, pedestrian activity), roadway information sources (e.g., signs, signals, markings), off-road facilities and activities (e.g., advertising signs, commercial activity), and in-vehicle displays and controls (e.g., other roadway information, use of navigation systems). Recommendation 4-26 provides further discussion of driver workload.

Recommendation 4-12: Avoid excessively conservative criteria

Warnings and displays that are unnecessary from the perspective of the individual driver can increase noncompliance. Overly conservative criteria for displays and algorithms can result in unnecessary delays and increases in noncompliant, risky behaviors.[3]

Rationale

Road users at an HRI may not comply with a warning if they do not perceive it to be reasonable (Lerner et al., 1989). In an effort to maximize safety, algorithms for initiating an ITS warning may be based on very conservative assumptions and large margins of safety. This may have the counter-effect of degrading respect for the system and increasing noncompliance. One means for dealing with this is to use ITS capabilities to customize messages for the immediate situation; Recommendation 4-20 addresses this.

Recommendation 4-13: Provide road user feedback regarding noncompliance and unsafe behaviors

Road users may have very poor awareness of the potential consequences of unsafe and noncompliant behaviors in response to ITS or other HRI messages. The normal driving experience rarely provides them with feedback that they have committed an unsafe act. Feedback can be provided through traditional or automated enforcement, public education, or intelligent feedback from roadside devices.

Rationale

Road users might engage in noncompliant and unsafe behaviors and never realize they did something potentially dangerous. For example, drivers may not engage in proper visual search at a passive crossing; but because train arrival is a relatively rare event, they may not experience any sense that they acted dangerously; or a driver may cross in front of an approaching train despite an ITS warning and not realize how close the event was or what the potential variance in crossing times might be. This lack of feedback results in what has been termed *benign experience*, where the driver's perception of the event reinforces the belief that the behavior was safe. Because the normal driving experience typically does not provide feedback about the actual risk of the behavior, some other means of conveying this must be sought. Enforcement is one strategy. This may not only enhance driver perception of crash risk, it also adds the likelihood of another risk (enforcement action) that may actually be more significant to the driver. Enforcement at HRIs is typically very limited, but automated enforcement technologies provide a means to implement enforcement through ITS. Public education is another way to provide feedback. Although organizations already exist to educate the public (e.g., Operation Lifesaver), more can be done to provide information about HRI safety. Finally, ITS technology suggests that it may be possible to provide direct feedback to drivers through sensing and communications. ITS technologies could sense unsafe vehicle actions and provide appropriate messages to drivers. A review of current systems, however, revealed no such ITS applications.

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[3] While agreeing with this general point, one reviewer pointed out that highway-rail grade crossings generate a "substantial amount of litigation and accidents resulting from less than conservative criteria may prevent suppliers from entering the market."

4.3.5 Distinguishing Safety-Critical Messages

Recommendation 4-14: Design safety-critical messages to be immediately recognizable as urgent safety alerts and discriminable from other messages

Safety-critical messages will not be effective unless they quickly and reliably draw attention and are immediately recognizable to the road user as being urgent and requiring immediate attention. To retain effectiveness, road users must be able to distinguish them from other types of displays (e.g., traveler information) and from other signals that might occur in the road users environment (e.g., cell phone ring). The best way to ensure a recognizable and discriminable format for safety-critical messages is through development of consensus standards. In the absence of standards, use warning elements familiar to road users through other applications, and select display parameters associated with high perceived urgency. Text warning messages, especially if they are presented in display locations that are used for other types of messages (CMS panels, in-vehicle consoles), are not adequate for urgent safety messages unless additional features exist to ensure immediate recognition of the safety urgency (e.g., color coding, acoustic alert).

Rationale

Considerations for safety-critical displays for roadside and in-vehicle ITS may be somewhat different (see Chapters 5 and 6), but they share this common requirement. Road users potentially encounter a range of messages from many different sources, and they will only respond quickly to these messages if the messages are clearly related to safety. A standard display, dedicated solely to urgent safety messages, is the ideal way to ensure road user recognition and to protect the message from confusion with other sources of signals and information. Although experts have stated the need for a consensus standard for ITS crash warnings (e.g., Lerner et al., 1996), no standards or regulatory body has proposed a standard, and no consensus practice is emerging. Consensus display aspects for the various modes of ITS message display should include color,[4] shape, icon, wording, dynamic elements (e.g., flash rate), acoustic signal/earcon, voice characteristics, and tactile attributes.

In the absence of consensus display features for safety-critical messages, consider using display elements that may already be familiar to road users. Fixed highway sign characteristics are obvious candidates. For example, road users are familiar with the black-on-yellow convention for warning signs and symbols for rail crossings. Current full-matrix CMS technology allows for color, icons, and movement in CMS signs, so that these do not need to be limited to monochromatic, all-text display.

Some signal parameters can help to convey a sense of urgency for visual and acoustic displays. Stimuli that are effective in conveying urgency, however, also tend to contribute to annoyance if there are false warnings [Also see: Recommendation 4-18] or to distraction [Also see: Recommendation 4-16]. Campbell et al.(2002) developed a useful set of guidelines for ITS in-vehicle visual and auditory displays.

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[4] A reviewer cautioned against the use of red; in this person's experience, red messages can cause undesirable slowing of traffic. Unless slowing is desired, this reviewer suggests the use of amber displays.

4.3.6 Choice of Message Display Mode

Recommendation 4-15: Consider the advantages and disadvantages of alternative display modes

The factors that relate to the choice of the mode of display—visual, auditory nonspeech, auditory speech, haptic, and tactile—are application-specific and are addressed in more detail in subsequent chapters. General advantages and disadvantages associated with each mode exist however, and these should be considered, whatever the application. Because each display mode has certain limitations, some redundancy should be provided in display modes, particularly for time-critical or safety-critical messages.

Rationale

Table 3 provides a general summary of the advantages and disadvantages of each mode. Visual and auditory modes are well researched. Relatively little research or experience with haptic signals to drivers has occurred. However, research (e.g., Lee, Hoffman, & Hayes, 2004) suggests that under at least some conditions, haptic signals can be rapidly responded to and may be less annoying than auditory signals. The importance of a given advantage or disadvantage, or the ability of the designer to overcome the disadvantage, is application-specific. Options for in-vehicle systems are generally greater than for roadway-based systems, which are largely limited to visual displays. ITS technologies, however, may be able to make greater user of other modes even for roadway displays. Chapters 5 and 6 provide further detail on display modes and characteristics for roadway-based and in-vehicle systems.

4.3.7 Unintended Consequences of the Message

Recommendation 4-16: Avoid driver distraction

Message displays should not require long-glance durations, excessive numbers of glances, long task completion times, or high cognitive demand. The amount of information that the driver must process should be easily dealt with in the time available under actual driving conditions. Specific considerations for distraction differ somewhat for in-vehicle and roadside displays; further recommendations are in appropriate chapters.

Table 3. General advantages and disadvantages of message display modes

Message Mode	Potential Advantages	Potential Disadvantages
Visual	• Message detail • Complex information • Can show spatial relationships • Can simultaneously provide multiple units of information • Message can remain as needed, no memory requirement • User control of information sampling • Color, shape, and icons can be language-free	• Eyes must be oriented toward display to detect • Limited foveal vision requires directed looks (visual distraction) • Susceptible to interference by glare, intervening objects • Effectiveness can be degraded by visual clutter (vision is a highly used information channel during driving) • Text messages require language literacy, reading takes time
Auditory Nonspeech	• No receptor orientation is required • Rapid reaction time • Can be directional • Orienting response	• Intrusive, annoying • Startle • Masking by environmental noise • Impinges on others • Ineffective for hearing impaired • Only general messages • Limited number of readily discriminated and remembered sounds
Speech	• No receptor orientation is required • Message specificity • Numerous different messages can be readily discriminated • Does not require learning of meaning	• More annoying than nonspeech • Time required to speak message • Intelligibility suffers in noise background • Impinges on others • Ineffective for hearing impaired • Ineffective for nonspeakers of the language
Haptic or Tactile	• No receptor orientation is required • Response compatibility (natural association) • Little used information channel	• Only general messages • Little experience or research on effectiveness, design parameters

Rationale

Distraction may be a problem for all roadway users. Distraction caused by focusing attention on a message display, however, is a particular concern for motorized traffic at the HRI because of the higher speeds of traffic. Displays that demand too much attention result in driver distraction, which results in deteriorated driving performance during the distraction episode. Such attention-demanding events also contribute to high driver workload. Driver distraction and workload may be related but are distinct issues. Distraction refers to the fact that road user attention can be devoted to some feature or event to such an extent that the road user does not devote adequate attention to all aspects of the driving task. High workload refers to the situation where a driver has too much information and/or too many requirements to be able to respond in the time available. Driver distraction and workload are concerns for ITS research and practice in general and are not specific to HRI applications.

Driver distraction problems are not limited to distraction by tasks or events unrelated to the driving task (such as cell phone use or roadside activity). Even driving-related tasks can be distracting if they require too much attention, depriving other driving-related activities of their required attention. While the designer of an ITS HRI display (or any other ITS display) wants to attract road user attention, the message should not require or encourage long glances or an excessive number of glances. For example, animated displays can be very attention-getting, but they can be captivating, and if duty cycles are long, viewers may be drawn to them for extended periods. Although a value of two seconds has sometimes been used to define the limit of an acceptably long glance (e.g., Driver Focus-Telematics Working Group, 2003), various factors may determine what is allowable. For example, if an in-vehicle ITS system presents some advance information that takes 2 seconds to process, users can time the moment to initiate the glance and may even be able to acquire the information with multiple, briefer glances. In contrast, if a roadway-based display requires 2 seconds of looking time, users have much less flexibility in when to look at the display. They may not be able to defer looking at the message, even if driver workload is high at the time the information is available.

Displays that present an amount of information that is excessive for the time available to process the information contribute to information overload. Some suggested criteria exist for CMS displays and in-vehicle displays, and these are considered in Chapters 5 and 6. Workload, however, is not entirely an attribute of a given display and task but rather includes the context in which the display occurs. For this reason, workload is a system concern, and Recommendation 4-26 further discusses this issue.

Recommendation 4-17: Consider the potential effects of automation complacency and risk compensation (behavioral adaptation)

The support provided to road users by an ITS application may result in undesirable changes in road user behavior that reduce (or even eliminate) the predicted safety benefits of the system. Two categories of behavioral changes occur as a result of experience with a system. One is a loss of vigilance and awareness as a result of over-reliance and trust in automation (*automation complacency*). The second (*risk compensation*) is where road users take advantage of increased safety provided by the system to engage in less safe behaviors (higher speeds, distracting activities). The ITS designer should analyze changes to the road user's task from the road user's perspective, with consideration of the potential motivations of the road user that might result in undesired behavioral changes. Post-implementation evaluations of actual driver behavior should be considered, including long-term evaluation to identify changes that may occur after extended experience with the system.

Rationale

Automation complacency is a clearly demonstrated effect but one that remains difficult to predict and quantify. Automation complacency refers to the case where a user over-relies on some automated aspect of the system, which can result in a failure to monitor the system, a failure to properly monitor the external environment, poor situational awareness, and poor decision making (Parasuraman, 1997; Endsley, 1996). Because the user takes a more passive role, benefits of automation that are intended by the designer as supplements to normal user vigilance instead serve to replace that vigilance. For example, an in-vehicle system that alerts motorists to approaching trains at a passive crossing may result in the drivers failing to search for approaching trains; if a system error occurs, the user's trust in the automated detection can result in a collision that might not otherwise occur. As a consequence of automation complacency drivers may be generally less aware of conditions at the HRI, such as the appropriateness of their approach speed, geometric demands, or the actions of other vehicles. The design challenge is to get road users to maintain normal alertness to the environment even though they have automated aids.

Another outcome of presumed safety improvements in the highway safety field is risk compensation (also termed *behavioral adaptation* and *behavior feedback*). This refers to the finding that road users give back part (or even all) of a safety benefit in return for some other perceived advantage. For this reason, the actual observed benefits of some safety technology frequently have not been as great as was predicted based on engineering analyses. Safety advances that have led to risk compensation behaviors include antilock brakes, center high mounted brake lights, studded tires, and improved lane delineation. Evans (1991), Smiley (2000), and Elvik (2004) address risk compensation issues. For ITS applications, considerable concern about potential changes in driver behavior has existed, but there has been little operational experience to assess these changes. For HRI applications, if drivers receive warnings about approaching trains, they may be more willing to approach HRIs at higher speeds, engage in other distracting tasks (e.g., cell phone use), or follow other vehicles more closely (with potential for vehicle-vehicle collisions).

The essential point about automation complacency and risk compensation is that road users may change their behavior if a change in the task or the information environment occurs. The ITS message provider cannot think in terms of a fixed driver behavior that the new information is being added to. Driver behavior will change in response to the new information, and this change may be undesirable from the public safety standpoint.

Recognizing the potential for automation complacency and risk compensation, how can the developer of an ITS HRI system predict and control these effects? Some detailed treatments of the effects of automation and variables related to it (e.g., Parasuraman, 1997) exist, but there is little systematic practical guidance for the ITS HRI developer. Some have suggested that risk compensation effects will be less pronounced if the safety benefit is transparent to the road user (e.g., Elvik, 2004), but this is often not feasible. Some have suggested the need for driving simulator or test track studies during system development to search for behavioral effects. These methods, however, may not be particularly practical and effective if complacency and adaptation develop over extended time and experience. Perhaps the most pragmatic recommendation is to recognize that these effects may occur and then to analyze the proposed message and display from the road user's perspective, considering the range of motivations that road users may have. These behavioral phenomena also suggest the need for both short- and long-term evaluation of driver behavior after implementation of an ITS system for HRI application.

Recommendation 4-18: Minimize annoyance

System designers should minimize annoyance while maintaining message effectiveness. Unfortunately, many of the attributes that contribute to display effectiveness (conspicuity, urgency) also are associated with annoyance. The use of graded warnings may help mitigate annoyance effects.

Rationale

Messages intruding on the road user have the potential to cause annoyance. Annoyance may lead to poor public acceptance of an ITS system, nonuse or system defeat, and degraded responding to messages. Message content, physical attributes of the display, and social and psychological factors may influence the annoyance of a message. The designer of an ITS message related to the HRI must consider trade-offs with annoyance while trying to achieve display conspicuity, comprehensiveness (to cover all users and situations), and completeness of information.

Road users may be annoyed by a message if they deem its content useless. Recommendation 4-9 describes various categories of nonuseful warnings. Research exists on the effects of false alarms (e.g., Chugh & Caird, 1999) or unreliable information (e.g., Campbell, Carney, & Kantowitz, 1998). Most existing research, however, has focused on how these attributes relate to driver behavior (e.g., response time, route decisions) and with few exceptions (e.g., Lerner, Dekker, Steinberg, & Huey, 1996) has not focused on annoyance and user acceptance. In general, a very thorough understanding of what is acceptable and how road users react to various categories of nonuseful messages is not available.

The same physical attributes that can make a message attention-getting can also make it more intrusive and annoying. For visual displays, these features include brightness and dynamic change (flashing, animation). For acoustic displays, these features include loudness, dynamic change, abruptness, and tonal attributes. In general, acoustic signals are more intrusive than visual signals, and speech messages tend to annoy drivers more than nonspeech signals (Lerner et al., 1996). Some indication also exists that users may respond to qualities of the voice, such as intelligibility, naturalness, and the apparent gender of the speaker. For example, a German carmaker reportedly had to change the voice providing navigation information because "many men refused to take directions from 'a woman'" (Vedantam, 2004).

The message parameters that relate to signal effectiveness tend to be correlated with annoyance as well Some limited research, however, has attempted to identify acoustic signal features that differentially effect annoyance and perceived urgency (e.g., Edworthy, Loxley & Dennis, 1991; Marshall, Lee, & Austria, 2001; Tan & Lerner, 1995). Because the qualities of conspicuity and urgency that contribute to a good warning display also may contribute to annoyance, one method to address this problem is to use graded warnings (e.g., Lee & Hoffman, 2004; Lerner et al., 1996). In this approach, the urgency of the warning message increases in stages or as a continuously graded signal. The most urgent (and potentially annoying) signal occurs only in the final, most critical stage. Therefore this imminent crash signal occurs rarely and briefly. An example of a multistage warning is a case where a visual display informs a driver if he/she is approaching an HRI at too great a speed, but an acoustic alarm is sounded only if the driver fails to respond and must make a severe braking action. Another possibility is to continuously increase the loudness and pulse frequency of an acoustic signal as the driver approaches the HRI at too high a speed.

Another aspect that may make a message annoying is that it may occur in the presence of other people and so a social aspect influences the driver's reaction. For example, a voice message to slow down will be heard by other passengers in the vehicle, and this could be embarrassing or aggravating to the driver and make the passengers uncomfortable. In an early application of collision avoidance technologies, a vehicle headway warning system was installed on a bus fleet. Bus drivers did not like that passengers were able to hear these audible warnings. Social concerns suggest the advantage of display modes that communicate more specifically to the intended recipient of the message. Haptic and tactile signals might be especially promising in this regard, although they are at this point little researched.

Roadway-based systems may have the potential to cause annoyance among people other than the road user for whom the message is intended. Sounds or lights may affect residents, businesses, or others in the area.

Recommendation 4-19: Anticipate road user misuse of information

Information presented to the road user for one purpose may be used for another purpose and may result in undesirable behaviors. Operational features of the system may also provide information that the road user responds to with undesirable behavior. Consider how the information content and operation of a message relates to individual user motivations. If the message is likely to induce unsafe behaviors, consider revising the message or discouraging the undesired behavior.

Rationale

Some road users may attempt to optimize their trips, even if they must perform illegal or risky acts. ITS information that is intended to assist the driver in making decisions about normal driving behaviors may instead be used as a cue that an inappropriate behavior may help to avoid some delay. For example, countdown displays that indicate the time to train arrival might tell drivers that they can beat the train if they speed sufficiently. Displays that inform waiting motorists of the remaining time until the train clears might lead to vehicles breaking out of a queue and making illegal turns. Operational features, beyond message content itself, may also induce unsafe actions. For example, some traffic signal pre-emption schemes may imply to turning traffic that they will lose their permissive turn phase and so induce erratic actions by impatient drivers. Vehicle-responsive barrier systems could motivate some drivers (particularly teens) to "play chicken" with the system or even try to trigger an activation. It may be difficult to predict the likelihood of some of these driver behaviors, but they nonetheless should be considered and dealt with before problems occur.

4.3.8 Message Appropriateness for Specific Road Users

Recommendation 4-20: Customize ITS messages for the current situation

Use available ITS information to adapt the message content, features, and algorithms to the current situation. Non-ITS messages and displays are necessarily based on assumptions about the road user, vehicle, environment, and other factors. If specific information on the actual situation can be used in place of assumptions, the message can be made more effective and credible.

Rationale

Many aspects of non-intelligent HRI displays are based on design assumptions, including vehicle characteristics (e.g., current speed, size, braking distance, clearance), driver characteristics (e.g., acuity, hearing, reaction time, alertness, familiarity with the area or particular HRI), environmental conditions (e.g., visibility conditions, weather and road surface, surrounding activity), and traffic characteristics (e.g., prevailing speeds, queues). For any given road user who encounters the display at a given time, many of these assumptions may be inappropriate. Often the necessary conservativeness of design assumptions will mean that warnings are overly conservative, reducing the credibility of the system. Warnings and other messages may be displayed at points in time that are not optimal for the specific road user. Message content may not be suited to the road user's information needs. On the other hand, under some conditions (e.g., poor visibility, queued traffic), even relatively conservative design assumptions may not be adequate to cover the requirements of a particular road user at a given time. Intelligent systems at the HRI may be able to collect relevant information (e.g., vehicle speed) as part of the system design or make use of information collected by other sources (e.g., roadside weather stations, traffic monitoring systems). Future systems may make more use of communication between the vehicle and the information system, so that the system may recognize the particular vehicle or driver.

For in-vehicle systems, current efforts also exist to develop technologies to sense driver distraction and alertness, to learn and adapt to individual driver behavior and capabilities, and to allow driver customization of display attributes. With better use of information, ITS HRI messages can avoid unnecessary warnings, provide more urgent alerts when needed, or give more specific information. For example, if the system recognizes vehicle attributes it could alert low clearance trucks to a low ground clearance (humped) crossing without subjecting other traffic to an unnecessary warning. If the system senses vehicle speed, a warning about an approaching train could be optimally timed for the driver, and, for drivers at higher speeds or projected collisions, the warning could be more extreme. If the HRI component of an ITS system communicates with a driver's route guidance system, the system could provide information about delays at upcoming HRIs only when the projected route would encounter that delay. Situation-specific messages may be advantageous in many other applications. Another important consideration, however, must also be taken into account. There may be system-level effects of customizing the message. For example, message customization may disrupt the consistency of content and location of ITS messages with traditional fixed roadway signing or traffic interaction effects might occur if different drivers get different messages. Recommendations 4-24 and 4-25 include further discussion of these system considerations.

Recommendation 4-21: Devise messages for effective communication with non-English-literate road users

Non-English-literate road users may be accommodated by presenting the message in language-free form, supplementing a text or spoken message with additional language-free elements, or (for in-vehicle ITS) providing an option for alternative languages.

Rationale

To accommodate multiculturalism and illiteracy, pictorial or symbolic highway signs are often used instead of text signs, particularly for regulatory and warning messages. Many in-vehicle ITS displays rely on visual icons instead of or in addition to word messages. Roadway-based ITS displays, however, often use CMSs with text messages. This fails to take advantage of the capabilities of current full-matrix CMS technologies to use icons or shape and color coding. The general point is that whether in-vehicle or roadway-based, ITS HRI messages must communicate to the general driving public just as broadly as traditional fixed signing does.[5]

Recommendation 4-22: Devise messages for effective communication with older road users

Many age-related changes in perception and cognitive capabilities are significant for the design of ITS messages. These may relate to display factors, such as choice of mode, visual display attributes, acoustic attributes, message format, display location, timing of messages, and amount of information. It is essential that message displays be appropriate for older drivers because they represent a significant and growing proportion of drivers and because older drivers may be more dependent than others for support from TCDs. The age at which certain perceptual or cognitive changes become significant in the driving population varies for different attributes, with some (e.g., accommodation, glare sensitivity) emerging meaningfully in the mid-50s and others (e.g., cataracts, reduced walking speed) typically emerging considerably later. However, a substantial drop in driving performance occurs, as indicated by crash experience as well as driver performance research studies, by the mid-70s (although this may not be so for any individual driver). Therefore, the capabilities of road users in their 60s and older should be considered in devising messages and displays, and those in their mid-70s may be at special risk and should be explicitly considered.

Rationale

Demographic changes in the population, as well as ever-increasing driving rates among older people, have focused concern on older drivers as a group. In 2002, 16 percent of the driving age population in the United States was 65 or older; by 2030, this group is projected to represent 25 percent of the driving age population and account for 25 percent of fatal crash involvements (Lyman, Ferguson, Williams, & Braver, 2001). With advancing age, crash involvement rates (on a per mile driven basis) increase, and fatal crash rates increase even more dramatically (Massie & Campbell, 1993). While fatal crash involvement is about 1.5 crashes per 100 million driving miles for those in their 40s and 50s, it is 2.5 crashes per 100 million driving miles for those aged 70–74 and 4.2 crashes per 100 million driving miles for those aged 75–79 (Insurance Institute for Highway Safety, 2005). For those 85 or older, the rate is 14.5 crashes per 100 million driving miles or about 9 times the rate of middle-aged drivers. Older drivers are, therefore, an important group to consider in the design of any highway safety system. Lerner, Ratte, and Walker (1989) reported that the overrepresentation of older drivers in grade crossing fatal accidents was quite similar to that (actually a little higher than) for fatal crashes as a whole. Particular concerns may

[5] One reviewer commented on his experience with the use of graphics on portable CMS displays. Because of the "coarseness" of the image, symbols (such as standard MUTCD graphics) that may be well understood on static signs may not be well understood in the CMS display.

exists for ITS applications because these are unfamiliar to the older motorist, have typically been developed without adequate regard to older users, and because older people are sometimes less willing to accept new technologies.

The list of factors that change with age is quite extensive, and the significance of any particular factor depends on the particular application. Table 4, adapted from Lerner, Benel, and Dekker (1995), lists driver performance variability factors associated with vision, audition, attention and cognition, anthropometry, psychomotor skills, body senses, and health status. Most of these factors have some association with age.

Staplin, Lococo, Byington, and Harkey (2001a, 2001b) developed a set of highway design guidelines and recommendations to accommodate older drivers and pedestrians. Although these recommendations do not encompass ITS, the documents contain extensive background and supporting rationale sections that show how age-related capabilities may be incorporated into highway practice.

Recommendation 4-23: Devise messages for effective communication with road users with disabilities

Adopt a universal design approach that respects the needs of all road users and encompasses their capabilities and limitations. Pedestrian traffic in particular may include individuals with a wide range of sensory or mobility impairments. Designers of ITS displays should anticipate the requirements of these road users and ensure that the systems are safe and usable for the entire population. This may require redundant modes of display to serve those users with either visual or auditory disabilities. The timing of messages, as well as physical aspects of the HRI, should include consideration of those with mobility limitations. Chapter 7 deals with design for pedestrian populations in further detail. Disabilities are of less concern in design for motor vehicle users because licensing requirements and visual and motor demands of the driving task exclude those with severe uncompensated impairments from the driving population. The primary concern is that the message display takes consideration of hearing impaired drivers and does not rely solely on acoustic messages.

Rationale

In recent years, designers of products and systems have increasingly recognized the need to accommodate the full range of potential users. The set of users may include persons with various disabilities or constraints, such as visual impairments, motor difficulties, or need for mobility aids. The transportation community has recognized the need to accommodate such users in the design of transportation facilities. This is reflected in various sections of the MUTCD (Federal Highway Administration, 2003), in other guidelines (U.S. Access Board, 2004), and from Barlow, Bentzen, and Tabor (2003). ITS HRI message design must consider the full range of users for appropriate visual attributes, acoustic attributes, display location, and temporal parameters. While this principle is true for any ITS HRI display, the diversity of the potential user population is a much greater concern for pedestrian applications. Chapter 7, Displays for Pedestrians, provides further discussion.

Universal design is an approach that begins the design process with recognition of the broad range of users and capabilities and integrates the features required for making the product or system accessible for everyone. This integrated quality distinguishes the approach from one that

Table 4. Driver performance variability factors (adapted from Lerner et al., 1995)

Vision	Audition	Attention, Cognition, Higher Order Perception	Anthropometrics	Psychomotor Skills	Body Senses	Health Status/ Pathologies
Spatial light perception • Contrast sensitivity • Static visual acuity Temporal light perception • Adaptation • Dynamic scene perception Color perception Movement perception • Dynamic visual acuity • Peripheral motion detection • Search/scanning capabilities • Looming (motion in depth) Night vision • Night myopia • Glare • Dark adaptation Depth perception Accommodation Peripheral field loss Ophthalmic conditions • Corneal damage • Senile miosis • Myopia/Hyperopia • Astigmatism • Presbyopia • Cataract • Glaucoma • Macular degeneration • Diabetic retinopathy • Detached retina • Retinitis pigmentosa	Tone perception Loudness perception Speech perception Frequency discrimination Intensity discrimination Temporal discrimination Sound localization Detection thresholds Auditory adaptation Noise tolerance Otiological conditions • Conduction deafness • Nerve deafness • Tinnitus • Presbycusis	Perceptual Judgment • Spatial/temporal judgment • Time • Distance • Speed/velocity • Relative speed • Trajectory estimation Perceptual organization and flexibility Perceptual construction Field dependence Risk perception Attention • Selective attention • Divided attention • Vigilance/level of attention • Attention switching • Attentional field/ useful field of view Information processing Information processing rate • Problem-solving skills • Learning capabilities • Reading speed • Reading accuracy • Cognitive style Memory • Primary/short-term • Secondary/long-term • Iconic	Body Dimensions Eye height (seated) Dynamic eye position Functional reach Mobility and Strength Overall range of motion (flexibility/dexterity) Head/neck mobility Foot/leg mobility Hand/arm mobility Hand dexterity Grip strength (dominant/ nondominant hand) Limitations of movement/flexibility Limitations of strength Handedness	Response Time • Simple reaction time • Complex/ disjunctive reaction time • Decision/choice reaction time • Control lag time Movement Capabilities • Movement speed • Movement precision • Movement ballistics • Continuous tracking • Preferred force/ effort • Maximal force/ effort	Mechanoreceptive/touch Proprioceptive/position in space Kinesthetic/movement Vestibular/balance	Functional age Dementia, Alzheimer's Depression Level of fitness Chronic stress Alcoholism Drug addiction Cardiovascular condition Cerebrovascular condition Arthritis Osteoporosis Diabetes mellitus Seizures, epilepsy Limb loss/paralysis Other specific diseases/ combinations of diseases Other neurological impairments

later adds additional features to accommodate certain users, after an initial design for typical users. Integration of concerns for all users from the beginning frequently results in designs that are better for everyone and may be more cost effective (and less stigmatizing) than adding on features later in the process. A good general resource for information on universal design is The Center for Universal Design, a clearinghouse operated through the College of Design at the North Carolina State University (http://www.design.ncsu.edu/cud/index.html).

4.3.9 System Considerations

Recommendation 4-24: Provide uniform messages and displays across information sources and sites

Information about the HRI coming from various sources should display the information in similar ways. This means that the display should be similar for HRI roadway messages at all locations and for in-vehicle systems from all providers. It also means that in-vehicle and roadway messages should be related, although they do not need to be identical. Visual messages should be uniform in terms of wording, icons, color, and shape. Acoustic messages should be uniform in terms of spectral characteristics, earcons, voice characteristics, and temporal patterns. Consensus standards or practices are required to insure uniformity across all systems, but these do not currently exist.

Rationale

Uniformity in displays is important to ensure comprehension, promote a rapid response, and minimize confusion. Standardization of wording, images, shape, and color are well established for fixed roadway signage, primarily through the MUTCD. Uniformity (treating similar situations in a similar way) is an explicit principle for traffic control devices (Section 1A.06). It serves to simplify the task of the road user because it promotes "recognition and understanding, thereby reducing perception and reaction time." Various current vehicle console displays and controls are likewise standardized through SAE, ISO, and others. Displays for roadway and in-vehicle ITS applications do not have the advantage of such uniformity. The development of consensus standards is strongly recommended. In the absence of consensus practices, designers or operators of HRI systems must take steps to promote uniformity for their users.

The uniformity of the display can be considered among roadway sites, among in-vehicle products, and between roadway and in-vehicle information sources. For roadway-based HRI displays, the appearance of the display should be similar at every site. Given the prototype nature of many ITS HRI applications, little similarity for similar cases may exist. For example, the second train warning displays in Section 3.2 portray a similar message in quite different ways. Even where the message is not identical, common message components should be similarly conveyed. For example, the means of indicating that the message is related to an HRI ought to share similar elements for various messages. For in-vehicle ITS displays, the appearance of the display should be similar for all products and vehicles. One barrier to consistency for in-vehicle displays is that manufacturers are concerned about product differentiation and want their systems to have a look and feel that is distinct from competing products. The variability of displays for similar messages is very evident in current in-vehicle ITS products for navigation systems and intelligent cruise control (e.g., Llaneras & Singer, 2002). For the HRI application, where time-critical safety warnings may exist, this nonuniformity may be more significant. Uniformity also relates to the relationship between roadway displays (whether fixed signing or ITS) and in-vehicle displays for the same message. Because of the very different viewing conditions and display alternatives, displays that are optimal for one application may not be ideal for the other. Nonetheless, the displays should be closely related to the extent possible. For example, Section 8B of the MUTCD (Federal Highway Administration, 2003) shows a number of text warning signs (e.g., NO GATES OR LIGHTS). An in-vehicle voice warning system should use consistent wording, unless a very strong case can be made for an alternative. Likewise, similar visual icons or colors should be used, unless a strong case exists for some alternative design. Uniformity is an important consideration for minimizing confusion and clutter, and the ITS developer should carefully consider this. Because standards already exist for fixed roadway signing, it is suggested that the features of these signs be considered as a starting point.

Uniformity refers not just to the specific message wording or icon but also to coding conventions. For example, in the visual mode, fixed signing uses color and shape to distinguish different types of warning, regulatory, and informational signs. Acoustic messages also might have similar coding conventions. For example, the same voice or alerting tone might be used for all safety-critical messages to distinguish these from other types of messages.

Recommendation 4-25: Provide compatible message timing among information sources

The timing of messages from multiple sources (e.g., in-vehicle ITS display and fixed roadway sign) of related information should be compatible. Compatible, however, does not necessarily mean at the same time. The optimal relationship may depend on various factors, including the type of message, the degree of redundancy, the amount or complexity of information, and the benefits of customization of the ITS message [Also see: Recommendation 4-20]. For ITS informational (notification) messages that are not safety-critical and that are highly redundant with roadway signs, presentation of messages from both sources at about the same time and place is advantageous. For other situations with urgent messages, complex messages, different message content, high workload, or major effects of customization, other timing relationships may be preferable. No straightforward guidance exists, and the decision must be based on a careful consideration of information processing demands and driver behavioral requirements.

Rationale

If two sources of information provide related or redundant information about some aspect of the HRI, it might seem reasonable to present that information from both sources at the same point in time. The situation, however, is more complex than that, and very little research on how to optimize the relationship between on-road and ITS messages has occurred. Campbell et al. (1998) provide the following guidance: "Notification messages presented on an ATIS should be paired with redundant roadway sign information." This guidance was based on driving simulator research and is carefully worded to constrain the scope of the recommendation. "'Notification messages' are those that simply inform drivers and allow them to decide on the appropriate action on their own" (pp. 7-12). This is in contrast to command style messages that suggest a particular action to take. Research has found benefits to simultaneous presentation only for the notification messages. The guidance also specifically states redundant information.

Simultaneous timing might not be ideal if the messages are complex because the driver might have difficulty processing and comparing both messages. If the messages are somewhat different in content but simultaneous, this might also be difficult to process. For example, a fixed sign message might indicate that a certain feature ahead, and, an ITS message might tell drivers to slow down if their speed is too high to deal with that feature. Simultaneous messages could conceivably slow responding to urgent messages, particularly if the two messages are in different forms. Furthermore, as noted in Recommendation 4-20, fixed signing must be located based on fixed design assumptions while ITS message timing can be customized for the current situation. This may result in differences in message timing between information sources but more optimal timing. Minimal research or operational experience exists to guide the consideration of timing of messages from multiple sources. It should not be assumed, however, that simultaneous timing is optimal for all situations.

Recommendation 4-26: Manage information demand and driver workload

The ability of a driver to respond to a particular message is a function of the amount and complexity of the information in that message, the time available to process and act on the information, and the other simultaneous demands on the driver from other information sources and other aspects of the driving task. ITS information about the HRI will not be fully effective if it occurs under high workload conditions and/or contributes substantially to high workload. Coordinating HRI information with other in-vehicle ITS information and in-vehicle tasks is a matter of systems integration [Also see: Recommendation 4-27]. Coordinating HRI information with roadway-based information displays and with the demands of the driving task requires a systematic analysis of driving task demands and information density. While no established, comprehensive format exists for such an analysis, the concept of information spreading in the Positive Guidance model (Alexander, n.d.; Lunenfeld & Alexander, 1990; Alexander & Lunenfeld, 1998) provides one framework for this. A simple computational model for driver information overload (Lerner et al., 2003) is also available as an aid to evaluating information load and comparing alternatives for display location and timing.

Rationale

Dealing with information intake, decisionmaking, navigating, maneuvering, scanning for hazards, and doing other tasks, while traveling at highway speeds, can be very demanding. The problem of high driver workload is an issue from two perspectives. First, displays of ITS messages about the HRI can contribute to high workload at certain locations. Second, displays of HRI messages may not be effective if workload from other sources is already high. Therefore, the demands imposed upon the driver by an ITS HRI message must be considered in the context of other information and other tasks that the driver must also deal with. Managing driver workload requires adapting the timing, location, and/or message content of the HRI display to the driver's information environment and operational environment.

An analytic approach known as Positive Guidance provides some systematic procedures for analyzing driver information requirements and "giving drivers the information they need to avoid hazards, when and where they need it, in a form they can best use it" (Mortimer, Blomberg, Alexander, & Vingilis, 2004). Although the procedure was not developed for ITS applications, it still provides a useful analytic framework. Lunenfeld and Alexander (1990), Alexander (n.d.), and Alexander and Lunenfeld (1998) describe Positive Guidance procedures.

Lerner et al. (2003) developed a simple conceptual model of driver information load that incorporates a weighting of four factors: (1) sign array information demand; (2) local information density in the region around the sign; (3) roadway demand (based on the presence of various roadway features); and (4) maneuver proximity (workload ramps up as the driver approaches choice points and areas where maneuvers are required). This model was based on empirical studies of fixed freeway signs (non-ITS) and generates quantitative, though crude, estimates of information load. It allows comparison of alternatives for locating messages. The computational model may help identify driver information load problems, but the model is limited for direct application to many HRI messages because it was developed on the basis of freeway driving.

Driver workload management involves coordinating HRI messages with in-vehicle task demands, as well as with roadway and environment demands. Of course, some in-vehicle activities are unpredictable. Predictable demands include those that are related to other ITS functions and vehicle displays. This involves the general issue of system integration, treated in the recommendation below.

Recommendation 4-27: Integrate ITS functions

Integration allows displays, controls, and timing for various co-located ITS functions to work in a coordinated manner [Also see: Sections 6.2.3 and 6.2.5].

Rationale

Integrating the various ITS functions provided to the driver is important for reducing confusions, assuring quick and accurate responding when needed, and managing driver workload. Most of the demonstration ITS systems of HRI services have been single purpose systems devoted to the HRI application. As ITS products and services proliferate, it will not be feasible to design each function as a stand-alone service. A range of ITS applications will have to share display and/or control features. This issue is greatest for in-vehicle systems, where many sorts of ITS services, as well as other sorts of in-vehicle communication or entertainment systems, may be present. However, it may also be an issue for roadway-based displays, if multiple systems exist or if a particular CMS is used for messages about things in addition to HRIs. ITS systems integration involves such considerations as prioritization of messages, the amount of information, compatibility of information displays and controls, user options, and so forth. Because the integration of ITS functions is primarily an in-vehicle issue, it is dealt with in Chapter 6.

Recommendation 4-28: Avoid inappropriate road user expectancies about the roadway network, railway network, and traffic control system

Design the ITS system to be compatible with road users' expectations. If road users are likely to have an inaccurate expectancy, take additional measures to overcome the expectancy. Such measures may include more emphatic signing, explicit messages about the expectancy, changes in the appearance of the roadway or HRI, or public education efforts.

Rationale

Road users do not just respond to what they see but also to what they expect. The system of roadways, railways, and HRIs that road users encounter will help determine their behavior at any particular location. This is also related to the road user's mental model of how the system works, discussed in Recommendation 4-7. Where road users have inaccurate expectancies about the system, responding may be slow or inaccurate, or messages may lack credibility. For example, if very few HRIs are in an area, and a roadway is relatively open and high speed with very few signals or roadside activity, the message of the road is that there are no impediments to free travel and no reason to slow down. Under these conditions, an ITS warning about an HRI ahead may lack credibility or may be responded to minimally until some visual verification occurs. Roadway users may have expectancies about the likelihood of HRI presence, about train speeds, about the expected times of trains, about the types of HRI control or ITS messages that might be used, about appropriate travel speeds, and so forth. The important consideration for the ITS developer is to recognize that road user response is related to expectancies and that expectancies should be brought in line with the actual conditions. Where a discrepancy exists, this may need to be directly addressed. For example, if train traffic in a corridor is normally low speed, but there is a single high-speed HRI, an ITS alert about an approaching train might be ignored at the high-speed crossing if the road user cannot see a train at the expected distance. In this case, additional information about train speed might be required.

Recommendation 4-29: Integrate ITS HRI displays and controls with the roadway traffic control system

Ensure that ITS messages about the HRI do not generate driver actions that are incompatible with other aspects of the traffic control system.

Rationale

This requirement is not unique to ITS displays; any HRI device should be integrated appropriately into the general traffic control environment. Messages should not be incompatible with traffic signals or other TCDs. While this is primarily an operational issue, human factors considerations exist as well. For example, an in-vehicle warning about an approaching train could cause a driver to slow on the approach to a green traffic signal (assuming the HRI is farther ahead), while following traffic without the in-vehicle system may not anticipate this slowing, resulting in traffic conflicts or crashes. Train pre-emption of traffic signals is another area where driver assumptions about signal sequences could lead to driver errors. Whether roadway-based or in-vehicle, the ITS message about the HRI should be considered in the context of the full traffic control environment.

5. Roadside Displays

5.1 Background

On modern roadways, roadway users receive information from signs, lights, auditory signals, pavement markings, texture treatments (rumble strips), barriers, and roadway geometry. Visual information for drivers is much more common than auditory or tactile signals. As new ITS technologies are introduced, it is likely that most roadside displays will continue to be primarily visual. In-vehicle displays and displays for pedestrians, however, may have substantial auditory or tactile components.

Although some ITS applications have included in-vehicle displays, their overall effectiveness will be limited until widespread penetration of the U.S. vehicle fleet occurs. Therefore, various types of roadside displays are likely to be the initial means of communicating ITS information for many applications.

This chapter focuses on general issues for ITS roadside displays (including displays mounted above the roadway) that may be relevant to HRIs. Part IV will cover human factors issues and guidance that are particularly relevant for specific applications; the majority of the recommendations in this chapter concern roadside visual displays, with a particular emphasis on CMS (also called dynamic message signs in the National Transportation Systems [ITS] Architecture), and animated displays. A few recommendations on the use of in-pavement lights and roadside auditory and tactile signals are included that may have some application at the HRI. Although several of the recommendations given here would apply to many types of displays, they are intended for newer display technologies such as CMS in applications that provide road users with real-time information about the HRI.

Detailed requirements for conventional TCDs, including roadside signs and other devices that are specified for use at HRIs, can be found in the MUTCD (Federal Highway Administration, 2003). At a minimum, new roadway displays should be consistent with the principles and standards in that document. For information specifically on the use of CMSs, Dudek's (2003) recent work on *Developing Standards and Guidance for Changeable Message Signs in the Manual on Uniform Traffic Control Devices—Final Report* is very thorough. Other useful information about the implementation of TCDs is given in the *Traffic Control Devices Handbook* (Pline, 2001), published by the Institute of Transportation Engineers (ITE). This chapter is not intended to duplicate the detailed and comprehensive guidance in these other sources. Rather, it draws on these resources to highlight human factors issues that are particularly relevant for innovative ITS displays for HRI applications.

While conventional signs present a fixed message at a fixed location along the roadway, CMSs can convey real-time information, such as traffic and road conditions, alternative routing, and provide other dynamic guidance, including information about HRIs. Dudek (2003) has defined six types of CMSs that are currently in use. Any of the CMS Types 2 through 6 may be useful for ITS applications at the HRI.

- *Type 1: Manual CMS.* Messages are changed manually without any electro-mechanical or electronic assistance).
- *Type 2: One-Message CMS.* Displays a single fixed message when activated or is blank when not activated.

- *Type 3: Fixed Message CMS.* Contains a small finite set of discrete messages. It may have several lines of text with each line changed independently of the others or a hybrid design where a word or symbol remains fixed for all messages and the other lines are changed among a finite set of messages.
- *Type 4: Speed Display CMS.* A matrix sign with two characters that has the capability of displaying a variety of numbers. Hybrid designs may have a fixed word or graphic that is displayed in addition to the two variable characters.
- *Type 5: Variable CMS.* A matrix sign with eight or more characters per line that is capable of displaying a very large variety of messages. Every pixel in a line is capable of independent activation.
- *Type 6: Dynamic CMS.* Contains a full-matrix screen with small pixels and is capable of displaying a very large variety of messages that can be shown in full-color and full-motion, including video images.

Intelligent signing and advanced display capabilities have been used in a few implemented HRI applications, such as second train warnings, but several other display types may be envisioned for HRI applications as well. Some examples of cutting-edge highway signing used in other applications are described below:

- *Example 1.* Figure 12 shows some prototype Graphic Route Information Panel (GRIP) signs that have been installed at the AVV Delft test center in The Netherlands (Roskam, Uneken, de Waard, Brookhuis, Breker, & Rothermel, 2002). In signs such as these, which show a road network, various segments are dynamically color coded to show advance information about traffic congestion, roadway conditions, or incidents.

Figure 12. Prototype GRIP signs, AVV Test Centre

- *Example 2.* The Road and Traffic Authority of New South Wales, Australia, has installed a CMS curve warning sign near the town of Kiama that uses color coding to indicate wet roadway conditions (Brisbane & Vasiliou, 2002). This illustrates how sign image, message, and color can be intelligently controlled based on the current situation. The sign display has three possible configurations, shown in Figure 13. The selection of the display is activated by a "moisture detection device, which is able to detect weather conditions and the amount of precipitation when raining as well as the pavement conditions in terms of dry/moist/wet." Under normal, dry conditions, the background sign panel is green, there is a curve sign (similar to a W1-2 Curve warning sign), and an advisory speed plaque of 65 km/h (left panel of Figure 13). If weather is raining and the road surface is dry or moist, the background panel remains green, but the curve sign is replaced by a Slippery When Wet sign (similar to a W8-5 sign), and the advisory speed is 55 km/h (center panel of Figure 13). If the road is wet, or if the weather is clear but the road is moist, the background color changes to red, and flashing lights attached to the sign are activated (right panel of Figure 13).

Figure 13. Kiama, NSW, Australia curve warning sign

- *Example 3.* An FHWA project (Hanscom, 2000) developed and evaluated an intersection collision warning system that included an animation component. It provides an example of intelligent signing using animation or through adding an active element to a standard highway sign. Active sign displays were used for the major road approaches and minor road approaches at a rural intersection test site in Arden, Virginia. The Collision Countermeasure System (CCS) used intelligent technology to provide motorists with information on potential conflicts. The minor road (Fleetwood Drive) is stop-controlled and described as having sight distance "extremely limited by buildings." Vehicle icons indicated the presence of potentially conflicting traffic. Figure 14 shows the signs for the major road and minor road approaches. The sign on the major roadway (Arden Road) was an activated sign but used a flashing icon, not animation. If a vehicle was poised to enter the intersection, a vehicle icon appeared on the appropriate leg(s) of a W2-1 cross road warning sign, and the icon flashed. A message panel also read "TRAFFIC AHEAD." The sign on the minor road showed animated movement of vehicles. When conflicting traffic was detected, an animated vehicle icon(s) moved across the display in the appropriate lane and in the appropriate direction.

Each of the three signing system technologies described above could be used to convey information to roadway users about conditions at the HRI. The GRIP signs shown in Figure 12 might be used to convey advance information about the HRI and provide alternative routing information. The CMS curve warning sign shown in Figure 13 might be adapted to provide dynamic advance information about the HRI, including warnings about train presence or weather related phenomena, such as a reduction in sight distance or slippery pavement conditions. The third example system, shown in Figure 14, has an obvious application at the HRI: to warn roadway users about approaching trains.

Figure 14. Collision warning signs for the major leg (left) and minor leg (right) of the intersection

Although their messages can change, CMS and other advanced roadside display technologies occupy a fixed location relative to the roadway (and to the HRI), and, as a result, they share many of the same human factors limitations as conventional signs:

- Roadside displays usually afford only brief viewing periods by drivers who are at large and rapidly changing distances and viewing angles. As a result, the length of a message that can be read by passing motorists is limited by their speed and by physical characteristics of the display which affect its legibility. Intervening objects, such as large vehicles or vegetation, can also limit viewing.
- Drivers may not notice the display if it has unfavorable placement against a complex visual background, or if other conflicting demands on the driver's attention occur during the critical viewing period.
- Once drivers pass a roadside display, they can no longer see it. This places a memory demand on drivers who must remember the information long enough to act on it.
- Ambient lighting on the display can vary dramatically throughout the day with changes in the relative position of the sun. Glare or extreme backlighting may reduce the legibility of the display.
- The reliability of roadside displays is constantly challenged by physical deterioration from exposure to weather, pollution, encroachments by nature, and extreme changes in temperature. Electronic displays in particular are vulnerable to lightning strikes and power surges. Roadside displays which fail too often will instill a lack of trust in ITS systems.
- As a result of their fixed, public locations, roadside displays may be read by all approaching roadway users, even those for whom the information is irrelevant. The number of roadside messages must be strictly limited to reduce the information processing demands on drivers and possible distraction by irrelevant messages. With this limitation, however, the information needs of individual drivers may not be fully satisfied.
- Modern technologies allow for complex displays with large amounts of text, multiple panels, variable color, dynamic elements (flashing, scrolling, animation), and even video. Little guidance exists regarding the use or misuse of dynamic and color aspects of CMS,

and this raises concerns about the potential to confuse or overload drivers as they approach and pass the display.

5.2 Key Human Factors Issues and Need for Guidance

5.2.1 Issue: Placement of Roadway Signs

For many types of standard signs and markings, including those related to HRIs in Part 8 of the MUTCD (Federal Highway Administration, 2003), the appropriate location of particular devices is well specified. This is not necessarily the case for roadway-based displays for ITS applications. Many different HRI ITS messages may use a fixed sign location, and the appropriate location will depend on message characteristics. For example, considerations for locating a message about a potential train collision at the HRI will be different than those associated with an active barrier device and very different from those associated with advance route recommendations related to a projected delay at an HRI. Because no specific guidance for innovative devices exists, decisions about ITS sign placement must rely on general principles regarding the location of TCDs. Signs should be located with respect to the hazard and driver decision points, other TCDs, driving task demands, driver expectancy, legibility concerns, and driver line of sight. A complicating factor for CMS displays is that a single sign may display a variety of messages, yet the ideal site for each individual message might not be the same.

5.2.2 Issue: Conspicuity versus Distraction

Roadway users must detect roadside displays if they are to receive useful information about the HRI. Display elements that draw attention serve the purpose of the display; however, displays must be conspicuous in the context of the entire driver-roadway system. Displays that draw the driver's attention away from other roadway elements and critical vehicle control tasks at critical times or hold the driver's attention too long are not safe.

Drivers must detect roadside displays against complex visual backgrounds, under a variety of lighting conditions, and with limited visual capabilities. Many factors affect the probability that a display will be detected. The following lists some of these:

Conspicuity Factors (from Ogden, 1990, cited in Hanscom & Dewar, 2001)

- Size (large signs are more conspicuous)
- Brightness (bright signs are more conspicuous)
- Boldness (large letters are more conspicuous)
- Edge sharpness (a border around the edge of the sign makes it more conspicuous)
- Contrast (high contrast, especially in brightness, between the device and its background aids conspicuity)
- Visual simplicity (a device is more easily detected against a simple background)
- Eccentricity (a device is more difficult to detect if it is more than 6 to 7 degrees from the line of sight)

Two other features of visual displays that are very powerful for attracting attention are motion and blinking (flashing). Although these features are commonly used on advertising signs, they are used only sparingly for TCDs because of concerns over driver distraction. The MUTCD (Federal Highway Administration, 2003) explicitly discourages elaborate advertising-type CMS display formats with animation or flashing to be used for displaying informational messages:

> Standard: When a changeable message sign is used to display a safety or transportation-related message, the display format shall not be of a type that could be considered similar to advertising displays. The display format shall not include animation, rapid flashing, or other dynamic elements that are characteristic of sports scoreboards or advertising displays.

Overly conspicuous displays may be distracting and annoying, particularly if the information is not relevant to the driver’s immediate needs. Recommendation 4-16 also addresses this general issue.

5.2.3 Issue: Legibility

Once drivers detect a roadside display, they must read and interpret the message. The legibility distance for a roadside display (maximum distance at which the driver can read the contents of the display) must be sufficient so that drivers have adequate time to read it before it is passed. Legibility distance, together with display location, must be adequate to give drivers enough time to read and act on information about hazards or alternative routes located at or downstream of the display. Legibility distance for roadside displays depends on many display-related factors (font type, font size, contrast between legend and background, use of symbols or graphics versus words), environmental factors (lighting, weather), and factors related to the roadway user (acuity, age). Hanscom and Dewar (2001) have summarized these factors. Legibility of symbols, icons, and other graphical elements has received much less attention from researchers, and a need for guidance in this area exists. The ability to dynamically vary color and action within a CMS poses additional questions about defining sign legibility.

5.2.4 Issue: Message Comprehension

Drivers may not understand messages even if the messages are successfully read within the time and distance available to view them. Isolated words and short phrases are particularly susceptible to misinterpretation, and the meaning of abbreviations, symbols, and graphical codes (e.g., color) may not be clear.

The physical size of displays and the reading time available to drivers limit message lengths. This results in messages that are often just a few words or symbols. For the meaning of such a message to be correctly understood, the message must tap drivers’ previous experience and match their expectations. Not all drivers, however, have the same level of experience or the same expectations. Drivers who are familiar with a particular section of roadway will have different expectations than those who are in the area for the first time. Older and younger drivers may have a tendency to interpret phrases differently because of cognitive changes that occur with aging or different levels of driving experience. Even recent experience may affect expectations. Drivers who take different routes before reaching the same roadside display may have different sets of expectations and may interpret the same message differently.

5.2.5 Issue: Driver Information Overload

Driver information overload is a concept developed to explain why driving performance deteriorates when drivers are faced with more information than they can process (Lerner et al., 2003). In environments that are too information-rich, drivers may react by decelerating severely, driving too slowly, making erratic lane maneuvers, or failing to consider other traffic. Reducing the driver's information load might reduce the frequency of these behaviors, which are obviously dangerous for the driver and for other roadway users. Information load depends on a complex interaction between the driver's expectations and decision requirements, and the complexity of the entire roadway environment, including nearby signage and traffic conditions. The placement of new roadside displays should be considered carefully, with consideration of the information load imposed on the driver in the vicinity of the display.

5.3 Recommendations

Table 5 groups recommendations for roadside displays under six topics. For each topic, the individual recommendation statements are given.

Table 5. Recommendations for roadside displays

Location of roadside signs

1. Locate roadside displays relative to the hazard or decision point.
2. Locate ITS roadside displays to avoid driver information overload.

Conspicuity and legibility of roadside displays

3. Make displays conspicuous but not overly distracting.
4. Use positive contrast orientation (legend lighter than background) for self-luminous roadside displays.
5. Keep luminance contrast of CMS between 8 and 12.
6. Adapt visual displays to ambient lighting.
7. Design displays for the visual acuity of licensed drivers.
8. Sequential (multiphase) messages may be used on CMS for non-crash avoidance messages, with certain constraints.
9. Limit message length for CMS displays.

Animation in roadside displays

10. Use animation selectively.

Ensuring that messages are understood

11. Follow a systematic message design process.
12. Use standardized words and symbols.
13. Use icons where appropriate.
14. Use color-coding selectively to enhance understanding.

In-pavement lights

15. Ensure that in-pavement warning lights, if used at the HRI, are installed and operated so that they are (1) effective, (2) consistent with other TCDs at the HRI, and (3) consistent with other traffic control applications of in-pavement lights.

Nonvisual roadside displays

16. Use acoustic signals to supplement HRI roadway visual displays.
17. Consider using tactile signals at the HRI.

5.3.1 Location of Roadside Signs

Recommendation 5-1: Locate roadside displays relative to the hazard or decision point

Locate roadway displays so that drivers have sufficient time to respond appropriately but not so far in advance that the information is not salient. For warning messages that have specific maneuvers or driver actions associated with them, design sight distance requirements are the usual means of defining a minimum distance from the hazard point. For informational displays associated with route choice (e.g., crossing status, predicted delay, route alternatives), sign locations are defined by the potential diversion points where the driver may change routes. Sight distance requirements are determined by driver perception-reaction time (PRT), maneuver time, and vehicle speed. A variety of site, hazard, and driver issues also influence these factors. General guidance on sight distance requirements and sign placement may be found in the MUTCD (Federal Highway Administration, 2003), the American Association of State Highway and Transportation Officials (AASHTO) (2001) *Policy on Geometric Design of Highways and Streets*, the ITE *Traffic Engineering Handbook* (Pline, 1999), and the *Traffic Control Devices Handbook* (Pline, 2001). Dewar and Olson (2001) provide a good discussion on the human factors considerations that influence PRT and other sight distance considerations [Also see: Recommendations 4-11, 4-25, 9-12].

Rationale

The required information presentation distance (calculated from driving speed, reading time, decision time, and maneuver time) and the legibility distance of the display (Hanscom & Dewar, 2001) determine the appropriate location of roadside signs in advance of hazards. Simple behavioral models and an assumed PRT value and vehicle speed are the bases for sight distance design equations. A PRT of 2.5 seconds is typically used for simple decisions about emergency braking (stopping sight distance), and the assumed vehicle speed is based on roadway design speed or the 85th percentile operating speed (whichever is higher). For more complex decisions, other assumptions are made (e.g., use of decision sight distance instead of stopping sight distance). However, for innovative ITS devices and applications, these simple models should be applied cautiously, taking into account factors (e.g., unfamiliarity, message complexity, driver decision issues) that might lead to increased PRT or maneuver times. Drivers want to receive information about their route, such as traffic conditions or status of an HRI, at locations where they can decide among alternate routes (Lerner & Llaneras, 2000; Lerner & Steinberg, 2000). The probability that a driver will divert to an alternative route based on information about the present route depends on the point in time that the driver receives such information (Allen et al., 1991; Khattak et al., 1991). Therefore, signs should communicate information sufficiently in advance of route decision points where opportunities to divert still exist.

Recommendation 5-2: Locate ITS roadway displays to avoid driver information overload

If HRI ITS displays are placed at points where other information sources and task requirements already put a high demand on the driver's information processing abilities, delayed or inaccurate responding, inappropriate slowing, erratic maneuvers, or tunnel vision can occur. Information load will be affected by other signs in the area, off-roadway distractions and visual complexity, roadway features (e.g., curves, lane drops), traffic interactions (e.g., lane changing, merging), and the proximity to maneuver points [Also see: Recommendations 4-11, 4-26, 8-2].

Rationale

The information load experienced by a driver over a section of roadway containing a visual display depends not only on the load imposed by that individual display (e.g., too much message content on a single sign), it depends on all of the TCDs (e.g., close spacing between signs) and roadway features in the local area, as well as several driver dependent factors, such as experience and expectations (Lerner et al., 2003). A roadside display with high information content or complexity may be acceptable in a location where the driver's information load from all other roadway features is low, but it may not be acceptable in an area where drivers already experience high information load from existing signs or decision demands. Consistent with this principle, Dudek (2003) has recommended that variable CMSs should not be located (1) within an interchange, (2) at locations where driver information load is already high due to guide signs and other types of information, and (3) in areas where high numbers of lane changing are anticipated by drivers in response to static guide sign information, merging, or weaving. The Positive Guidance Technique (Alexander & Lunenfeld, 1998; Lunenfeld & Alexander, 1990) provides some methods for properly distributing sign information. Lerner et al. (2003) provide a model for computing driver information load, but it is limited to freeway applications.

5.3.2 Conspicuity and Legibility of Roadside Displays

Recommendation 5-3: Make displays conspicuous but not overly distracting

Roadside displays should be made conspicuous through visual features, such as size, brightness, edge sharpness, contrast with the background, and proximity to the driver's line of sight, but display formats which promote lengthy or an excessive number of glances should be avoided. Roadside displays seen by drivers should not be overly conspicuous or require such long reading times that they encourage long glances (greater than two seconds) or an excessive number of glances (at-track displays intended to be viewed and read while drivers are stopped at the tracks are an exception to this general rule) [Also see: Recommendations 4-1, 8-10, 8-22].

Rationale

Sensitivity of the visual system increases and decreases in response to the spatial, temporal, luminance, and chromatic visual features in the environment. Such changes in visual adaptation provide for good visual function over a wide range of luminance levels, and these changes support the detection of changes or differences from prevailing background conditions. Drivers are likely to detect targets that differ from their surroundings with respect to luminance, color, motion, size, and so forth. Visual contrast between roadside displays and their visual environments can enhance their conspicuity. Long duration glances at roadside displays are not consistent with safe driving behavior. Although typical glance durations are on the order of 1.0–1.5 seconds (see Green, 2001 for review), glances away from the road that exceed 0.75 seconds are often considered long, particularly in traffic (Beijer, 2004). The lack of attention to control and guidance aspects of the driving task for more than 2 seconds is likely to lead to situations where the driver is forced to react immediately upon returning attention to the roadway. Lane deviations, emergency braking, and possible rear-end collisions are all likely to occur if drivers make long-duration glances. Driver eye glance studies of roadside signs have found that complex dynamic signs can result in a substantial number of long glances (Beijer, 2004). Animated displays may be particularly problematic when the animation sequence cycle is long. Full-motion video images are not recommended for use in TCDs unless drivers see them only when stopped.

Recommendation 5-4: Use positive contrast orientation (legend lighter than background) for self-luminous roadside displays

Rationale

Luminous backgrounds can cause spreading of light across the display that reduces legibility and at night, which increases the likelihood that the display will be an annoying source of glare for roadway users. Evidence exists that positive contrast messages may be read from greater distances than negative contrast messages. In laboratory studies, Garvey and Mace (1996; as cited by Dudek, 2003) found a 29 percent improvement in nighttime legibility distance with positive as opposed to negative contrast.

Recommendation 5-5: Keep luminance contrast of CMS between 8 and 12

The luminance contrast of roadside CMS should be between 8 and 12 under all daylight conditions.

Rationale

Luminance contrast is a ratio defined as $C = (L_{on} – L_{off}) / L_{off}$ and is determined empirically under daylight conditions by measuring the luminance of the entire character matrix illuminated (L_{on}) and the luminance of the display when all display elements are off (L_{off}). At night, where the luminance of the display in the OFF state tends toward zero, the luminance of the display elements in the ON state, rather than luminance contrast, should be used to determine legibility. Dudek (2003) recommended the values given above because higher contrast levels lead to irradiation, a condition where the lighter surface elements tend to bleed onto the darker surface elements, causing the message to appear blurred. Lower contrast levels are more difficult to read and result in a shorter legibility distance.

Recommendation 5-6: Adapt visual displays to ambient lighting

The luminance of the display elements should be at least 1000 candelas per square meter (cd/m^2) during the day and much lower (approximately 30–50 cd/m^2) at night. Consider developing displays that adapt to changes in the position of the sun, perhaps with movable shades or by slight changes in the physical orientation of the display with respect to the roadway.

Rationale

Dudek (2003) recommended the luminance values above based on legibility studies on simulated CMS and literature reviewed by Garvey and Mace (1996). During the day, the amount of skylight and direct sunlight falling on the roadside display changes over the course of the day. Ambient light reflected from the face of the display toward the roadway user can reduce the local luminance contrast between legend and background elements on a roadside display making the display characters look washed out and difficult to read. This reflected light may be partially reduced by slight changes in the orientation of the display with respect to approaching roadway users. More practically, the ON display elements should have higher luminance levels during the daytime to compensate for the ambient illumination, increasing the local contrast between the display legend and background. At night, the ON display elements should have lower luminance levels to avoid dazzling glare from the display and to improve legibility.

Recommendation 5-7: Design displays for the visual acuity of licensed drivers

Provide an adequate legibility distance for drivers with visual acuity of 20/40.

Rationale

Most jurisdictions require high luminance visual acuity of at least 20/40 (6/12) while wearing corrective lenses, if necessary, to obtain and maintain a driver's license. Legibility requirements, therefore, should be based on a design driver with 20/40 (6/12) acuity. For persons with this level of visual acuity, Hanscom and Dewar (2001) recommend a legibility index of 30 feet/inch for sign letter height. Legibility distances tend to be greatly reduced for many older drivers, particularly at night (Dewar, Kline, Schieber, & Swanson, 1994, cited by Hanscom & Dewar, 2001).

Recommendation 5-8: Sequential (multiphase) messages may be used on CMS for non-crash avoidance messages, with certain constraints

For displays that are read by drivers who are moving, non-crash avoidance messages may be presented across more than one temporal phase (page), subject to the following limitations:

- A maximum of two phases may be used, with each phase limited to three lines of text.
- The entire message should be readable at least twice by drivers traveling at the speed limit or 85th percentile operating speed.
- The message should be divided so that each phase contains a complete thought.
- If more than one CMS is visible to roadway users, then only one such sign shall display a sequential message at any given time.
- No visual transition effects, such as fading, dissolving, scrolling, or motion, should be used.

Urgent crash avoidance messages should be simple and should be presented in a single phase to convey the warning as quickly as possible. For displays that are to be read by drivers and other roadway users who are stopped at the HRI, the CMS may be used to present messages with more than two phases depending on the nature of the message. Messages that contain an urgent time-sensitive warning (such as a second train warning) must be presented quickly to inhibit the movement of the road user.

Rationale

The most important consideration for splitting a CMS message into phases is to enhance message comprehension. A two-phase display can enhance comprehension of complex messages because more words (information) can be presented in the limited display space over two temporal phases rather than in a single phase. In other cases, complex messages that can fit entirely within the space limits of a single phase of the CMS display may be split into two shorter information chunks to enhance readability and comprehension.

Most guidance developed for CMS message phasing has focused on the use of CMS on limited access highways and expressways rather than on conventional roadways and low volume roads where at-grade HRIs are more likely to be found. Nevertheless, the specific limitations given above have been selected for presentation here because they are the best available guidance at this time. In the future, as more trials are done with CMS technology on arterial and secondary roads, these limits may be changed.

The MUTCD (Federal Highway Administration, 2003) has the following statement (Section 2E.21), concerning the use of CMS on freeways and expressways:

> Standard: Messages shall be centered within each line of legend. If more than one changeable message sign is visible to road users, then only one such sign shall display a sequential message at any given time. A three-line changeable message sign shall be limited to not more than two messages. Techniques of message display such as fading, exploding, dissolving, or moving messages shall not be used.

Thus, this standard covers the specific Limitations 1, 4, and 5 given above. Limitation 2 is taken from Jones' (2001) chapter in *Traffic Control Devices Handbook* (Pline, 2001), and Limitation 3 is based on Dudek's (2003) guidance. The exact phase duration used should be based on factors such as legibility distance and reading time required. Studies by Dudek and Huchingson (1998; cited by Dudek, 2002) and Dudek, Trout, Booth, and Ullman (2000; cited by Dudek, 2002) found no significant differences in driver recall (or preference) for two-phase messages presented at 2 seconds per phase or 4 seconds per phase. The shorter time per phase may be preferable for roadways with higher traffic speeds to ensure that drivers will be able to read the entire message twice while they are within legibility distance of the display. Because the display may first become legible or noticed while it is in either phase, each phase of the message should make sense by itself and provide a complete thought. Pedestrians and other road users who are stopped at the HRI may allocate more visual attention to roadside displays than drivers who are engaged in controlling their vehicles. Therefore, visual displays for these road users may be somewhat more elaborate than those to be read by approaching drivers.

Recommendation 5-9: Limit message length for CMS displays

Message length should be limited by legibility distance, traffic speed, and display type. For typical 18-inch high characters, under the most favorable daylight lighting conditions, and with traffic speeds below 35 mph, a CMS can display five units of information. No more than four units of information should be displayed when operating speeds are 51 km/h (35 mph) or more. The maximum amount of information presented should be reduced for higher traffic speeds or less favorable lighting conditions.

Rationale

Road users take more time to process complex messages than simple messages. The concept of an information unit has been described in the literature to help quantify the amount of information contained within message displays. While no universally accepted definition exists for what constitutes a unit of information, the general principle is that the longer the message, the more processing time will be required. Detailed guidelines on the amount of information to be presented in variable CMSs have been worked out by Dudek (2003) based on a review of the literature. Dudek (2003) developed detailed guidelines on the amount of CMS information load. A unit of information is the answer to a question that a roadway user might ask (for example, what? where? when?) or the unit of data that a driver might use to make a decision. For CMSs, a unit of information is usually one to three words (occasionally four words). The maximum number of units of information to be presented depends on the type of display technology, lighting conditions, and traffic speed. Other more general guidelines presented by Campbell et al. (1998) define an information unit in terms of the number of key nouns and adjectives contained within a message. For example, the phrase, "HIGH SPEED TRAIN APPROACHING" would constitute a message with four units of information. To help drivers keep their attention focused on the roadway, information messages should not present more than three to four units of information.

5.3.3 Animation in Roadside Displays

Recommendation 5-10: Use animation selectively

Animated displays may be used for pedestrian applications or for displays located at the HRI (such as second train warnings) that are seen only by the stopped vehicles in the cue waiting to cross the HRI. Animated displays that are to be seen by drivers in moving traffic should be applied selectively for situations where a clear need to capture the driver's attention exists and where animation provides an efficient way to communicate the message (perhaps as an alternative to multiphase messages, or to communicate with non-English-literate roadway users). If seen by drivers of moving vehicles, animated sequences should have a short duration so that they do not encourage long glances.

Rationale

The apparent motion effects produced by animation are highly conspicuous and may be effective for use as warning messages, especially for displays that must be located outside of road users' central visual fields. To date, however, there has been very little research to support the use of animation in traffic control devices (Lerner et al., 2004).

An animated eyes display (an animated pair of eyes that alternately look to the left and right) was tested at a stop sign controlled HRI in Polk County, Georgia (van Houten, 2001). The display which activated for 10 seconds when a vehicle was detected on the roadway was intended to encourage drivers to slow down and search for approaching trains. The authors reported that the percentage of drivers who crossed the tracks at greater than 24 km/h (15 mph) decreased from 5.5 percent to 2.8 percent, and the percentage of vehicles exceeding 48 km/hr (30 mph) dropped from 2.1 percent to 0.6 percent from the baseline period to the sign-activated period. Although the observed reduction in speed may be partially attributable to the distracting effects of the novel display itself, rather than to its message, the speed data suggest that further trials are warranted for animated eyes displays at the HRI.

Because of the potentially distracting effects of apparent motion for drivers who must attend to many other motion cues to safely guide their vehicles through traffic, animation should be used sparingly for HRI applications.

5.3.4 Ensuring that Messages are Understood

Recommendation 5-11: Follow a systematic message design process

A systematic, rigorous design process should be followed when developing messages for new roadside displays. Candidate words, abbreviations, and icons used to denote HRI and train events on roadway displays should be tested with roadway users to ensure understanding and appropriate reaction before being implemented [Also see: Recommendations 4-6, 7-5].

Rationale

The usability of informational displays is much improved by following an iterative, user-centered design process (Koyani et al., 2003). Campbell, Richman, Carney, and Lee (2002) have outlined an example of such a process for icon development.

Recommendation 5-12: Use standardized words and symbols

A standardized set of words, abbreviations, and icons related to HRI information should be developed for roadside displays. These should be based on familiar, commonly understood terms and symbols so that conventional roadside signs, CMSs, and in-vehicle displays are consistent. TRAIN should not be abbreviated, and the abbreviation, HRI, should not be used on roadside displays at this time. Standards on acceptable and unacceptable abbreviations, as given in the MUTCD (Federal Highway Administration, 2003), should be applied to roadside displays [Also see: Recommendations 4-5, 4-24, 6-7, 8-6, 9-8, 9-9].

Rationale

By using a consistent set of terms, symbols, and icons for HRI information, roadway users will quickly learn the meaning of messages and will react appropriately. Certain abbreviations are already standardized for use on traffic control devices. The MUTCD (Federal Highway Administration, 2003) lists many acceptable and unacceptable abbreviations. Some of these, which may be particularly relevant to messages about the HRI, are given here:

Acceptable Abbreviations

- LFT = left
- HAZMAT = hazardous material
- N-BND, S-BND, E-BND, W-BND = (North bound, South bound, etc.)
- MIN = minute(s)
- MI = mile(s)
- MPH = miles per hour
- RHT = right
- RXR = railroad crossing
- SPD = speed
- WARN = warning

Acceptable Abbreviations only when [preceded by] or (followed by) a prompt word

- AHD = ahead (fog)
- BLKD = blocked [lane]
- CHEM = chemical (spill)
- PREP = prepare (to stop)

Unacceptable Abbreviations

- Xing = crossing (may be used only for crossings other than HRIs)
- CLRS = clears
- DLY = delay

"TRAIN" should not be abbreviated because of its importance and short length. In addition, the abbreviation "HRI" should not be used on roadside displays because this term is not in common usage, and most roadway users would be unlikely to recognize it. New abbreviations should be tested with roadway users to ensure an adequate level of comprehension, such as correct interpretation by 85 percent or more of the people tested (e.g., Durkop & Dudek, 2001).

Recommendation 5-13: Use icons where appropriate

Icons may be considered for use on roadside displays based on the following indications: (1) quick and accurate recognition of a message is necessary (warnings); (2) visual or spatial concepts need to be conveyed; (3) the driver will be performing a visual search of alternatives; (4) the amount of information on the display is limited, and presenting textual information will take up too much space; and (5) an icon already exists and has a generally accepted meaning [Also see: Recommendation 6-7].

Rationale

These considerations for the use of icons were adapted from those given by Campbell, Richman, Carney, and Lee (2002), based on a review of expert judgment and experimental data concerning the use of icons for in-vehicle displays. The general principles given here apply equally well to the use of icons on roadside displays for drivers and pedestrians.

Recommendation 5-14: Use color coding selectively to enhance understanding

If large areas of color are used as background or primary legend on roadside displays, they should conform to the standard color meanings and usages specified in the MUTCD (Federal Highway Administration, 2003). Color alone should not be used to convey information, but limited amounts of color can enhance understanding as an element of a graphical display.

Rationale

The use of color for roadside signs has been standardized so that it is used consistently for TCDs, and roadway users have come to expect certain colors to have specific meanings within the context of roadway systems. Color coding has been used in some nonstandard roadside displays to indicate travel time, congestion, road condition, route options, and facility status, little research has occurred on the benefits, problems, or optimal usage of color coding for these applications (Lerner et al., 2004). Color, by itself, is not a signal that can be interpreted correctly by all drivers. Approximately 8 percent of men and 0.5 percent of women have a reduced ability to discriminate colors (congenital color blindness). Others have acquired color vision deficiencies due to disease or exposure to toxins or drugs. Additionally, for targets viewed in the periphery of the visual field, all drivers have reduced color discrimination ability between 25–40 degrees from the fovea and nearly complete color blindness beyond 40 degrees (Judd & Wyszecki, 1975).

5.3.5 Pavement Lights

Recommendation 5-15: Ensure that in-pavement warning lights, if used at the HRI, are installed and operated so that they are (1) effective, (2) consistent with other TCDs at the HRI, and (3) consistent with other traffic control applications of in-pavement lights

Care must be taken when selecting and installing in-pavement lights to ensure that they will be visible to approaching motorists. Installing in-pavement lights across travel lanes at the HRI and activated by approaching trains is consistent with their use at pedestrian crossings, where in-pavement lights activated by a pedestrian signal motorists to yield the right-of-way. The installation of in-pavement lights across the travel lanes at the position of the advance warning sign (W10-1), however, is not recommended.

Rationale

Pavement lights, like all TCDs, must be effective if they are to be used. According to the MUTCD (Federal Highway Administration, 2003), to be effective any TCD must do the following:

- Fulfill a need
- Command attention
- Convey a clear, simple meaning
- Command respect of road users
- Give adequate time for proper response

In addition, concerning the placement and operation of traffic control devices, the MUTCD states that

> Placement of a traffic control device should be within the road user's view so that adequate visibility is provided. To aid in conveying the proper meaning, the traffic control device should be appropriately positioned with respect to the location, object, or situation to which it applies. The location and legibility of the traffic control device should be such that a road user has adequate time to make the proper response in both day and night conditions.

In-pavement lights installed at the HRI, and activated by an approaching train, may increase the conspicuity of the crossing, especially at night. Installation of in-pavement lights across the travel lanes at the location of the advanced warning sign, however, is not recommended because the meaning of the lights and proper driver response may not be clear. Drivers who suddenly brake or stop at these lights may violate the expectations of following drivers, increasing the risk of rear-end collisions. Placement of in-pavement lights across the roadway in advance of the HRI is inconsistent with their use at pedestrian crosswalks, and the train tracks where the position of the in-pavement lights indicates the hazard position.

Adequate visibility of in-pavement lights is also a concern. Lights must be sufficiently bright to be seen in daylight, and lenses must be kept clean and free of debris that reduces the intensity of the light seen from the approaching driver's position. Because of the potential for damage, lights must be mounted flush with the roadway where snowplows are used. This can create problems for aiming the lights optimally where the roadway approaching the HRI slopes at a different angle than the area where the lights are mounted.

5.3.6 Nonvisual Roadside Displays

Recommendation 5-16: Use acoustic signals to supplement HRI roadway visual displays

Roadway-based acoustic signals may be used to supplement HRI roadway visual displays but not as the primary message mode. Speech-based roadside signals are not appropriate for messages intended for motor vehicle operators. Acoustic supplement signals should not be confusable with train horns or wayside horns. Acoustic signals should be audible under actual road user listening conditions [Also see: Recommendations 8-24, 11-9].

Rationale

Audible signals are not normally used for roadway-based TCDs. Bells or other audible warnings that may be used in conjunction with flashing lights and gates at HRIs are one exception. Another is the use of audible tones to aid visually impaired pedestrians at pedestrian crossings. Train-based horns are another audible warning signal, and roadside horns are an infrastructure-based alternative for some situations (train horns, whether train-mounted or wayside, are not seen as ITS applications and not treated here). In these cases, audible signals supplement visual displays, which are the primary mode of communication. Visual displays are appropriate as primary roadside-based message modes because some road users may be hearing impaired, listening environments may be unfavorable, and road users expect visual messages. Acoustic signals may also be intrusive on the surrounding community. Nonetheless, acoustic signals may be useful supplements for some HRI applications. They can be used as conspicuity enhancements where visual displays are located in positions where they may not be highly noticeable. When used in this way, the sound source should be co-located with the visual display so that the road user’s attention is oriented toward the visual message. Audible cues may also be useful in conjunction with intelligent sensing of usual conditions at or near the HRI (e.g., arriving train, reduced visibility conditions, cued traffic, and slippery roads). If intended to be heard by vehicle operators, the signal should be detectable within the vehicle under typical listening conditions, which may include closed windows, climate control system noise, engine noise, entertainment system audio, and environmental noise. Because of the critical nature of train horn warnings, supplemental auditory signals should not be confusable with train horns. Guidance for the use of audible tones for pedestrian use may be found in Section 4E.06 of the MUTCD (Federal Highway Administration, 2003). Auditory alerts may be useful not only for visually impaired pedestrians but also for general pedestrian traffic when attention to visual displays may be questionable (e.g., second train situations). Intelligent technologies may allow for speech-based messages with specific information. Speech messages are not appropriate for messages intended for motor vehicle operators, where listening conditions will degrade intelligibility. A review of literature and applications revealed no examples of speech-based messages for pedestrians. Pending any research that demonstrates some advantage, speech-based messages are discouraged because nonspeakers of the message language(s) would not understand them.

Recommendation 5-17: Consider using tactile signals at the HRI

The development of any dynamic tactile displays for roadway users (such as train activated pop-up rumble strips) should be guided by consideration of the needs of bicyclists and motorcyclists, as well as the full range of vehicle types, and should be tested extensively to assess driver reactions. Active tactile displays for pedestrian crossings may be especially useful for those who have visual or auditory disabilities.

Rationale

Although dynamic tactile signals have not been demonstrated at HRIs, train status information could be used to control roadway surface features Tactile displays, such as rumble strips and speed bumps, are used effectively as traffic calming devices; however, many drivers find them annoying and circumvent them. A tactile warning device upstream of the HRI, which is only active during train events, may have the potential to reduce train-struck-by-vehicle accidents and vehicle-to-vehicle rear-end crashes for drivers stopped at the HRI, without annoying drivers during periods with no train activity. Any such device, however, must be safe for use by motorcycles and bicycles under various weather conditions. Road users' responses to such a device should also be evaluated. Startle responses are possible for those who do not expect the device to be deployed, and risky behaviors, such as driving around the device (into an opposing traffic lane), may occur. For pedestrians, pole-mounted touch panels or in-ground, vibro-tactile displays activated by an approaching train may be designed to mimic, amplify, and anticipate the natural ground vibrations that occur when the train moves through the HRI. Although all pedestrians may benefit from the redundant warning cue presented by tactile displays, this form of display may be particularly useful for pedestrians who are blind or deaf and may not notice visual or auditory signals.

6. In-Vehicle Displays

6.1 Background

Designers of in-vehicle systems that incorporate HRI information should seek to understand and accommodate the needs of all drivers who are likely to use such systems. For example, developers and manufacturers should serve the needs of older drivers who tend to require longer glances to read information and who tend to experience retention problems for complex messages. Older drivers may be particularly at risk when using in-vehicle devices if design decisions about size, complexity, information content, and location of displays and controls are made on the basis of the perceptual, cognitive, and psychomotor skills of either the average driver or the 85th percentile driver.

Many other human factors issues are relevant to the provision of HRI information through in-vehicle devices. Concerns relate to the physical and operational properties of the devices (location of the display, size, brightness, clarity and detail of the image, amount and quality of information supplied by the system, etc.), as well as to drivers' behaviors and perceptions related to their use (e.g., impacts on drivers' mirror sampling, frequency of use, duration of glances to the device time-sharing, and ability to maintain situational awareness).

This chapter addresses how to provide in-vehicle ITS information. The guidance is generally not specific to messages about the HRI but applies more broadly to vehicle-based ITS communications and interactions. A variety of sources provide guidance and recommendations for in-vehicle displays. In this document, which is specifically concerned with HRI applications, it is not appropriate to address all of the general human factors issues of in-vehicle displays, controls, and communications. At the same time, however, the appropriate design of in-vehicle systems may be critical for the success of various HRI applications. Therefore, this chapter introduces and discusses many of the important human factors issues and provides guidance (drawn from more general sources). Additional guidance, standards, and recommendations may be found in various sources, including those listed here:

- *Preliminary Human Factors Design Guidelines for Driver Information Systems* (Green et al., 1995)
- *Preliminary Human Factors Guidelines for Crash Avoidance Warning Devices* (Lerner et al., 1996)
- *Human Factors Design Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO)* (Campbell, Carney, & Kantowitz, 1998)
- *In-Vehicle Display Elements Task F: Final In-Vehicle Symbol Guidelines* (Campbell, Richman, Carney, & Lee, 2002)
- *Statement of Principles, Criteria and Verification Procedures on Driver Interactions with Advanced In-Vehicle Information and Communication Systems—Draft Version 3.0* (Driver Focus-Telematics Working Group, 2003)

6.2 Key Human Factors Issues and Need for Guidance

6.2.1 Issue: Choice of Display Mode

How information is presented can influence driver performance, and a need for guidance exists regarding the most appropriate display mode (auditory, visual, haptic) to use in vehicles. Information about HRI may be presented through different display modes, depending on the urgency and complexity of the information, but should be integrated with other driver information systems. Previous research on visual and auditory in-vehicle information systems is applicable to the design of systems to present HRI information. For example, for navigation systems, voice guidance is generally associated with better route navigation performance compared to electronic maps (Srinivasan & Jovanis, 1997). Complex audio messages, however, can lead to large numbers of navigation errors (Walker, Alicandri, Sedney, & Roberts, 1990). Simple, short messages (four elements or less) can be presented safely while driving (Graham & Mitchell, 1997; Llaneras, Lerner, Dingus, & Moyer, 2000). Increasing the time or duration that messages are displayed or providing a repeat function to alleviate some of the workload and pacing issues may aid drivers, particularly older drivers.

The use of visual displays in the automotive environment raises issues, such as the location of the display, appropriate number of lines of text, need to capture driver attention, and the ability of drivers to process messages while maintaining safe driving performance. Popp and Farber (1991) found that a display positioned directly in front of the driver results in better driving performance (lane tracking and obstacle detection) than a peripherally mounted display. Head-Up Displays (HUDs) provide an alternative for presenting information to drivers, but these types of displays may not be the best option for dynamic text presentation because they may be distracting. The number of lines of text presented on a display appears to impact driving performance. Tijerina, Kiger, Rockwell, and Tornow (1995) examined workload impacts of text message displays in the context of an on-road study with 16 professional truck drivers ranging in age from 32 to 60 years. Message displays consisting of one, two, or four lines of text were presented on a 7-inch cathode ray tube or CRT display mounted above the instrument panel. Results of this on-road study found that two- and four-line text messages had substantial detrimental effects on visual allocation and lane keeping performance. These more demanding text displays were associated with more glances to the display, more steering reversals, fewer accelerator inputs, and more lane position variance and lane keeping errors.

Llaneras, Lerner, Dingus, and Moyer (2000) examined how attention demand changes as a function of visual and auditory display characteristics and task type. Results indicated that auditory format and speech rate significantly affect vehicle steering (steering variability), speed (average, minimum, and variance), and headway (average and variance). Displays using embedded prose, for example, yielded more variance in steering wheel, vehicle speed, and headway driving measures. Results also suggested that accelerated speech displays (225 words per minute) can be used without sacrificing driver comprehension or driving performance. Furthermore, in contrast to visual displays, auditory displays had relatively low workload, enabling drivers to maintain a driving profile similar to that adopted during baseline driving; older drivers appeared to benefit most from auditory displays.

Previous work, including that mentioned above, provides useful background information for the design of auditory displays, as well as visual text displays. These studies and others form a basis for guidance about how HRI information should be presented in the vehicle.

6.2.2 Issue: Driver Distraction

Time spent away from processing the road scene while scanning in-vehicle displays, or attending to other nondriving-related secondary tasks, can significantly impair a driver's ability to control the vehicle and detect and react to external events. A major consideration in the design of in-vehicle displays, therefore, is the glance frequency and duration to a display while driving. Zwahlen, Adams, and Debald (1988) suggested that the number of glances to displays be limited to three, with glance durations under 2 seconds. The challenge for telematics system designers is how to efficiently (and safely) present electronic text, particularly dynamically displayed text, to drivers when display space is limited. Driver distraction is believed to be a factor in a substantial proportion of collisions. Because distraction is hard to measure and can be defined in many different ways, it is difficult to put a precise estimate on its contribution to collisions. However, based on existing reports (e.g., Treat, 1980; Hendricks, Freedman, & Zador, 1999; Wierwille & Tijerina, 1994), a rough order-of-magnitude estimate would be that about 20–25 percent of collisions may be related to distraction. Vehicle-based personal computers, ITS, communications devices, entertainment centers, and other emerging technologies have the potential to further compound the problem. A recent inventory of in-vehicle telematics devices sponsored by NHTSA (Llaneras & Singer, 2002) found systems with a number of potentially distracting design elements, including displays that present large amounts of information and incorporate dynamic elements; unrestricted access to complex, multistep, and demanding tasks while driving; and systems that provide for multiple functions and expanded capabilities. Truck driver distraction due to in-vehicle technologies may differ from the automobile driver problem for a number of reasons. These include differences in the types and functions of in-vehicle devices, differences in device placement or design, the truck cab environment, trucking-related tasks, and vehicle control demands, among other aspects.

6.2.3 Issue: Information Overload and Integration of Advisories and Warnings

As the number of independent warning (and information) systems proliferates, it may be common for a single vehicle to be equipped with multiple systems. That is, the same vehicle may have several in-vehicle warning systems, including train approach warning, forward and side collision warning, lane departure warning, and drowsy driver warning systems that were all independently developed and installed. The concern is that the various collision warning systems (CWS) designed to alert drivers to potential and imminent collisions may themselves become hazards or may loose their effectiveness when more than one is present in the same vehicle. Developers must fully understand how issuance of multiple independent alerts can negatively affect driver performance and the ability to respond to threats.

6.2.4 Issue: Behavioral Adaptation

Also of interest is whether drivers change their driving behavior as a result of their perceived changes in the risk of driving that these technologies provide. This type of change in behavior has been called behavioral adaptation and refers to the response of drivers to the introduction of new technologies in vehicles. The changes in behavior can be positive, negative, or neutral in terms of their effect on safety. For example, if drivers perceive that the new technology makes the driving task easier, they may drive more miles or drive faster. Another possibility is that drivers are able to benefit from the feedback provided by some systems or by the reduced workload and maintain their performance for a longer period of time. Different adaptations can occur in the short and long term. In the short term, drivers may respond to the novelty of the device but in the long term may find it annoying and thus ignore it or turn it off. All of these behaviors play a role in the real world effectiveness of newly introduced technologies.

6.2.5 Issue: Message Prioritization

With the advent of new systems that convey in-vehicle messages to drivers, such as roadside information, including road-condition warnings and travel advice, and vehicle-status messages, including collision warnings and vehicle operating conditions, concern exists that these systems may distract or overburden drivers with information. Such messages may also compete for attention with other systems within the vehicle and may cause a lack of focus on operating the vehicle safely. Message prioritization is intended to provide the basis for selecting which set of messages that are competing for the same display time and space should be presented to the driver. Several standards development organizations are developing guidelines and industry-recommended practices to insure the clear and concise presentation of multiple ITS messages to drivers. SAE, for example, has outlined a procedure for determining the orderly presentation of information to drivers while taking into account time sensitivity, travel distance, and display space limitations. It describes a method for prioritizing in-vehicle messages and/or displayed information based on a defined set of criteria. Each criterion has a fixed number of levels that are used to rate or rank a given message or information item to determine its prioritization value. The prioritization value is then used to determine the priority in which simultaneous, or overlapping, in-vehicle messages are presented to the driver. This recommended practice is intended to lead to the development of consensus standards for the prioritization of in-vehicle messages that are displayed by ITS.

6.3 Recommendations

Table 6 groups recommendations for in-vehicle displays under seven topics. For each topic, the individual recommendation statements are given.

Table 6. List of recommendations for in-vehicle displays

Choice of mode
1. Use visual displays to present spatially-based information and for long or complex messages (provided the vehicle is not in motion).
2. Use audible presentation modes for delivering high priority information requiring immediate action.
3. Use speech-based messages when high degree of detail is required and the meaning of other sounds may be ambiguous or forgotten under stress.
4. Consider using visual icons rather than text-based messages.
5. Consider using auditory icons in place of tones or beeps.
Visual display attributes
6. Locate visual displays for warning systems within the driver's field of view, without obstructing the driver's view of the dash controls, gauges, or mirrors.
7. Use standardized icons and graphics for in-vehicle warnings.
8. Ensure that visual display elements (characters, text, graphics, etc.) are sufficiently large to be read in moving vehicles and that the information can be assimilated with a few brief glances.
9. Use some means to attract driver attention to the display (e.g., flashing lights) if the system relies exclusively on a visual display to communicate information (no audible warnings/messages).

Auditory (nonspeech) display attributes

10. Audible warnings should be sufficiently loud so they can be detected and understood by the driver in the presence of background noise.
11. Limit the number of different warning tones to three or four easily discriminable sounds.
12. Auditory alerts should be used to notify drivers of high-priority messages and changes in status, as well as augment signage information.
13. Tonal signals (nonverbal auditory signals) should use a frequency range between 500 and 3000 Hz and burst durations of about 100 ms.

Speech display attributes

14. Avoid the use of synthetic speech displays.
15. Messages that require an immediate response should consist of a single word or short phrase and should be understood immediately.
16. Provide a means for repeating speech messages.
17. Ensure that messages are easily differentiated from other speech in vehicles.

User control and adjustment

18. Complex information and control interactions should not be designed for use in a moving vehicle.
19. If multiple input or adjustment controls are present, design the controls so drivers can easily differentiate among the controls and their functions.

Location of controls

20. Locate system controls within the driver's reach, with the most frequently used or accessed controls closer to the driver's line of sight and reach.
21. Match the type of control used to the types and levels of functions to be controlled.

Operational issues related to in-vehicle systems

22. At actively controlled crossings with gates, in-vehicle warnings should be timed (coordinated) with the activation of the crossing gates or other active warning devices.
23. Provide system compatibility and integration.
24. Indicate system status.
25. Tailor information presented within the vehicle to match the driver's specific situation and needs (e.g., approaching an HRI, waiting at an HRI, EMS personnel).
26. Evaluate the potential effects of behavioral adaptation for new in-vehicle systems.

6.3.1 Choice of Mode

Recommendation 6-1: Use visual displays to present spatially-based information and for long or complex messages (provided the vehicle is not in motion)

Displays that present lengthy or complex information should be accessible only when the vehicle is not in motion. Urgent or high priority messages that require immediate attention generally should not be presented visually; if the visual channel is used to communicate messages requiring immediate action, it should be used as a secondary communication means and should be prominently displayed and be accompanied by an alerting tone [Also see: Recommendation 4-15].

Rationale

The most appropriate mode to present in-vehicle information to drivers depends upon the nature of the information and the urgency with which driver response is required. In general, warnings used to alert drivers to a hazard (e.g., approaching train) should convey the level of the hazard (caution, warning, danger), recommended action to avoid the threat, and consequences of inaction. Information that is purely informative should generally be presented visually; auditory presentations may needlessly distract and annoy drivers. Avoid presenting complex visual displays for in-vehicle systems while the vehicle is moving because the visual demand required to access and read the displayed information may significantly interfere with drivers' ability to control and steer the vehicle. Drivers should be able to assimilate visual information within a few brief glances. Glance duration should be brief enough not to adversely affect driving (single glances should generally be under 2 seconds). Several methodological procedures are available to ensure that in-vehicle visual-based displays are suitable for presentation while the vehicle is in motion (Society of Automotive Engineers, 2004).

Recommendation 6-2: Use audible presentation modes for delivering high priority information requiring immediate action

Drivers perceive auditory information quickly and reliably which makes the auditory channel well-suited for the presentation of warning information to drivers. Some applications may benefit from a redundant visual display in situations where additional detail may be required to interpret the audible signal [Also see: Recommendation 4-15].

Rationale

Auditory displays can quickly capture drivers' attention. For this reason, auditory displays are ideal for short and important warnings and messages (typically using nonspeech forms). Nonspeech auditory displays in combination with visual displays are powerful; they have the advantage of drawing attention while being able to specify the nature of the problem. These types of multimodal displays decrease reaction time when compared with visual signals alone. Thus, different modalities can be used in combination to enhance the overall message. Because audible displays can annoy, they should be used sparingly and designed to avoid overloading or annoying drivers.

Recommendation 6-3: Use speech-based messages when high degree of detail is required and the meaning of other sounds may be ambiguous or forgotten under stress

Speech messages should not be used for time critical tasks because they can be inefficient and subject to masking [Also see: Recommendation 4-15].

Rationale

Voice messages can transmit much more information than simple tones, but they are also subject to interference from ambient noise. Speech-based messages should be used sparingly since voice output can interfere with human speech communication. Speech should only be used if drivers have enough time to listen to the full message and to choose the correct action. More time is required to deliver a speech message than to alert the driver through other modes. For this reason, speech displays are not recommended for presenting specific information of a dynamic nature (Lerner et al., 1996). Older drivers, in particular, can have difficulty understanding voice messages in the presence of background noise. Speech-based systems should allow for adjustments in volume and the capability to repeat messages. Speech messages should be simple with the most important information presented at the beginning of the message (and repeated at end, optionally). If no alerting tone can be provided, supplement visual information with redundant speech information.

Recommendation 6-4: Consider using visual icons rather than text-based messages

Visual icons may be used instead of text-based messages under the following conditions: (1) when the amount of display space is limited, (2) when icons currently exist and are well known and accepted by the population, and (3) when quick and accurate recognition of the message is required [Also see: Recommendation 4-15].

Rationale

Icons are graphical symbols intended to transmit specific information and have the advantage that they are not language dependent (they can be universally recognized and understood across a diverse range of populations). Moreover, well designed symbols and icons are recognized more accurately and faster than text. Nevertheless, unless icons are already commonly associated with an idea or object, many icons must be learned. Good symbols and icons are detectable, discriminable, and meaningful to drivers. It is important to test and evaluate comprehension levels for icons before implementing them; ISO recommends comprehension levels of at least 66 percent. In some cases, auditory information should supplement icon messages to make the message clearer or more salient. For example, symbols used for a warning, should be accompanied by textual or spoken speech (this captures attention and allows for instructions if feasible). Combine icons with auditory information when presenting high priority alerts and warnings and when static visual displays change to announce the presentation of the visual information.

Recommendation 6-5: Consider using auditory icons in place of tones or beeps

Auditory icons may be used to aid in the interpretation of the signal and speed driver response [Also see: Recommendation 4-15].

Rationale

Auditory icons are representational sounds that have specific stereotyped meanings (e.g., train horn,[6] tire skidding). Because auditory icons represent familiar environmental sounds that intuitively convey information about objects or actions, they are generally better recognized than conventional tones or beeps whose meaning must be learned. To be effective, auditory icons must be identifiable as having relevance or conveying inherent meaning and should be used as a means of augmenting visual presentation of in-vehicle messages (not meant as a sole means of presenting messages). Meaningful sounds in the HRI context include a train horn or bells; these will likely capture driver attention because they are associated with danger or hazard at the HRI. No more than six auditory icons should be used to minimize memory demands (Campbell, Richman, Carney, & Lee, 2002).

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[6] One reviewer, while agreeing with the general recommendation, took exception to the use of the train horn as a potential auditory icon, stating that a train horn "has its own specific meaning and should not be used by anything other than the actual train." The reviewer believes other applications of the horn sound may undermine the actual train horn's effectiveness, especially since other applications may require conservative triggering criteria and hence inappropriate warnings. Although the authors of these guidelines agree with this caveat, they feel that if a horn icon had demonstrated strong benefits for certain applications, it should not be ruled out with consideration of the trade-offs.

6.3.2 *Visual Display Attributes*

Recommendation 6-6: Locate visual displays for warning systems within the driver's field of view, without obstructing the driver's view of the dash controls, gauges, or mirrors

Displays should be positioned (or designed) to minimize glare or reflections that make it more difficult to extract information. Visual displays should also be positioned in relation to their importance and frequency of use.

Rationale

Visual displays that carry information relevant to the driving task and visually intense information should be positioned as close as possible to the driver's forward line of sight to reduce total eyes-off-road time. Driver's forward line of sight refers to the direction of the driver's gaze out the windshield and onto the road ahead. A display that is too low in the vehicle may divert the driver's attention from the roadway. When installed, the system should not obstruct or interfere with the driver's field of view of the roadway, existing vehicle controls, or displays required for driving (Stevens, Quimby, Board, Kersloot, & Burns, 2002). Displays located within the driver's field of view will also take advantage of a drivers' peripheral vision to detect movement ahead of the vehicle. Popp and Farber (1991) recommend display screens be mounted 15 degrees below horizontal and that they do not exceed 30 degrees. More specific equations concerning the maximum downward viewing angle are approximately in agreement with this value (Driver Focus-Telematics Working Group, 2003). Desirable display locations are high on the instrument panel near the area directly in front of the driver. Important visual information should be positioned near the forward line of sight (dashboard). If a Head-Up Display (HUD) is used, however, it should not cover the driver's central field of view because it may obscure external objects. The information presented on the HUD should be limited to a few elements that can be quickly extracted from a virtual image that is 2.5-4 meters from the driver's eyes (Stevens et al., 2002).

Recommendation 6-7: Use standardized icons and graphics for in-vehicle warnings

Consensus-based standard icons should be used for ITS displays to indicate an HRI and an approaching train. No such standards currently exist for in-vehicle displays. Icons incorporating the W-10 advance warning sign or R15-1 Crossbuck may be helpful but are not sufficient by themselves. If icons (or graphic formats) are used to communicate in-vehicle warning messages, they should have a direct and obvious meaning; drivers must be able to quickly recognize and interpret their meaning. Use symbols that the driver already associates with the object or idea [Also see: Recommendations 4-5, 4-24, 5-12, 8-6, 9-8, 9-9].

Rationale

Drivers are familiar with the standardized W-10 advance and R-15 Crossbuck signs, and they are present at all HRIs. Because they are also present in the external environment, they provide redundant cues to drivers in a familiar form. Nevertheless, because a significant proportion of drivers may not understand the underlying meaning of these signs, it may be necessary to supplement these with prescriptive information (supplemental text, audio, or training) to clarify their meaning and direct behavior. Very few studies have examined use of warning formats (such as graphics) to communicate presence of a train at an HRI. Work by Hoekstra, Williams, and Green (1993) suggests that the following alternate formats for an in-vehicle warning may be effectively used to communicate train presence: a text-only message "TRAIN AT CROSSING" or the W-10 sign graphic with supplemental lights above the standard RXR sign. The In-Vehicle Signing System for School Buses at Highway Grade Crossings used by Minnesota Department of Transportation used a W-10 graphic; however, this graphic was intended to communicate the presence of an HRI rather than a train at the crossing. Other applications have used animated train icons to indicate the presence of a train (Maryland Mass Transit Administration and Sabra, Wang, & Associates, Inc., 2001; PB Farradyne, 2002). The diversity of icons used in these examples illustrates the need to have a standardized, unambiguous message or sign graphic. Symbols must have a clear meaning; otherwise the message will not be understood and will be open to misinterpretation. FHWA has developed a set of human factors design guidelines for in-vehicle display icons, addressing key design issues such as icon recognition, interpretation, and legibility (Campbell et al., 2002).

Recommendation 6-8: Ensure that visual display elements (characters, text, graphics, etc.) are sufficiently large to be read in moving vehicles and that the information can be assimilated with a few brief glances

Maximize legibility of visual displays assuming glances of 1–1.5 seconds in duration.

Rationale

Information presented on visual displays should enable drivers to read and acquire the information easily and quickly without overburdening or distracting drivers. Limit the amount of text information displayed. Present brief messages that minimize what the driver must read. Design displays so that drivers are able to quickly extract information. Often displays can be designed so that the information remains displayed until the driver acknowledges it, rather than having the pace of information flow controlled by the system. Type size, contrast, and typeface will influence legibility and how quickly information can be read. Green et al. (1994) recommend using plain typefaces (e.g., Geneva, Helvetica) to maximize legibility and using mixed case instead of all capital letters for messages in excess of two or three words. Display brightness, image size, and resolution also contribute to legibility. A contrast ratio of at least 3:1 is recommended. Characters to be read in moving vehicles should subtend a visual angle of at least 24 minutes of arc (Stevens et al., 2002).

Recommendation 6-9: Use some means to attract driver attention (e.g., flashing lights) if the system relies exclusively on a visual display to communicate information (no audible warnings/messages)

For in-vehicle systems, the use of an audible warning tone or message in association with a visual display is strongly recommended. Text displays for use in vehicles should be preceded by a tone and should be limited to a few words [Also see: Recommendations 4-1, 5-3, 8-10, 8-22].

Rationale

Drivers may not detect warnings and alerts presented via visual displays because they require drivers to glance at the display. Audible cues, warnings, and alerts do not have this limitation. As a result, safety and advisory warnings should precede an auditory alert (alerting tone) to draw attention quickly. For in-vehicle systems, a short alert tone (100–150 ms in duration) may be used to capture driver attention and draw them to the visual display message. If no audible display means is possible, flashing of any visual image can be used to attract attention. Blinking the display “on” and “off” (with a frequency between 2–10 Hz and a duty cycle of 50 percent) can also serve as an effective (fast and conspicuous) means of capturing attention (increases conspicuity). Objects placed in the periphery (away from main line of sight) can also be more readily detected when blinking. Blinking elements on displays can be annoying, so their use should be limited. Because driver overload and distraction away from the task of driving can be an issue for in-vehicle systems, avoid use of unnecessary attention-grabbing techniques.

6.3.3 Auditory (Nonspeech) Display Attributes

Recommendation 6-10: Audible warnings should be sufficiently loud so they can be detected and understood by the driver in the presence of background noise

Audible message output should be 15–35 dB above the ambient noise level. This can be achieved by automatically adjusting audible warning output or muting onboard radios/stereos.

Rationale

Auditory output should be audible under a range of driving conditions. The volume should be adjustable over a reasonable range (between 50 dB and 90 dB). Avoid using sounds louder than 90 dB(A). The signal should not exceed ambient noise by more than 25 dB because this may elicit a startle response. A tone that is not sufficiently intense relative to background noise impairs intelligibility; too intense produces startle (Benekohal et al., 2000). For urgent warnings requiring immediate action, use signal strength of 70–90 dB(A) and signal-to-noise ratio of 10–15 dB(A). It is desirable to have the signal level automatically adjust to the background noise. The system may also allow drivers to adjust volume within a range of +/-10dB(A).

Recommendation 6-11: Limit the number of different warning tones to three or four easily discriminable sounds

Create distinguishable sounds by varying two or more of the following: (1) spectral content, (2) pulse duration, (3) pulse shape, and (4) temporal pattern. Vary at least two acoustic parameters to ensure discriminability. The duration of a signal burst should be between 100 and 150 ms.

Rationale

Warning tones should be distinguishable and readily recognizable. Drivers’ ability to remember the meanings of sounds is limited and decreases under high workload situations. Certain attributes for tonal warnings are important. These include conspicuity, discriminability, meaning, urgency, and response compatibility. The signal parameters cited in the recommendation are primary characteristics that relate to these attributes. Short signals are less likely to interfere with other signals, and they allow for more flexibility in coding. Warning tones should have some sort of time-varying or intermittent character because the perceptual system is geared toward change. Drivers may be most sensitive to temporal aspects of tonal signals. Consider using rates of 1–8 beeps per second or warbling sounds that rise and fall in pitch.

Recommendation 6-12: Auditory alerts should be used to notify drivers of high-priority messages, to communicate changes in status, and to augment signage information

Alerts are intended to address information presented to drivers before the presentation of a message; they capture the driver's attention.

Rationale

An alerting tone should precede high priority visual information because they have been shown to increase accuracy and speed response to message. High-priority alerting signals should be used for time-critical events requiring an immediate response.

Recommendation 6-13: Tonal signals (nonverbal auditory signals) should use a frequency range between 500 and 3000 Hz and burst durations of about 100 ms

The optimal range varies with age. Frequencies less than 2000 Hz are recommended for older drivers. Avoid continuous tones because they are easy to habituate. Signal burst duration should be approximately 100 ms to ensure detection and should be 10–15 dB over ambient noise levels.

Rationale

Alarm dimensions, such as speed, repetition rate, and pitch, can affect the perceived urgency of the alarm. The time characteristics appear to be the most efficient parameters to vary (so as to vary perceived urgency). Imminent crash warnings, for example, should convey more urgency than cautionary warnings. Changes in perceived urgency can be accomplished by varying signal intensity, oscillations in pattern, repetition rate, and fundamental frequency. Drivers must learn tones or beeps (require association between signal and message). If corresponding visual information exists, both should be presented simultaneously.

6.3.4 Speech Display Attributes

Recommendation 6-14: Avoid the use of synthetic speech displays

Rationale

Intelligibility is one of the key parameters for a successful speech display, addressing understandability of the speech and comprehension of the information. Spoken information should be highly intelligible and reliable so it can be synthesized or digitized from real human speech. Synthetic speech is generally less intelligible or preferred than recorded human speech and can potentially increase driver workload. Vocabulary must be familiar and based on known population stereotypes.

Recommendation 6-15: Messages that require an immediate response should consist of a single word or short phrase, and they should be understood immediately

Nonurgent messages should contain a maximum of seven units of information (approximately seven words). The most important information should be presented at the beginning and/or end of the message because it is easiest to recall [Also see: Recommendation 4-14].

Rationale

Speech warnings should be brief and concise, generally between one and three words. Longer messages are preferred if time is not a critical factor. Under time sensitive situations, drivers should be able to understand the message immediately. Longer messages require more processing time than shorter messages and are subject to forgetting. Presenting information in order of importance allows drivers to quickly focus and extract critical information.

Recommendation 6-16: Provide a means for repeating speech messages

For urgent speech messages (warnings), automatically repeat the message up to three times. If time permits, precede speech outputs with a short auditory nonspeech signal (e.g., chime) to attract attention. Drivers should have a control that allows them to easily repeat nonurgent speech messages.

Rationale

Unlike visually displayed information, spoken messages cannot be referenced once the information has been provided. Unless some mechanism allows drivers to easily repeat spoken messages, (at their discretion), the information can be quickly forgotten. Although repeating messages can help alleviate this problem, repeating nonurgent speech messages numerous times may annoy or irritate drivers. Providing an audible cue in advance of the message prepares drivers to attend to the message. A given speech warning or messages should be presented no more than three times. Repetitions should occur in immediate succession. If the duration of the condition is less than the time required for all three presentations, the speech message should be terminated once the threat is no longer present.

Recommendation 6-17: Ensure that messages are easily differentiated from other speech in vehicles

Rationale

When more than one auditory signal exists to alert drivers to different types of conditions (existence of HRI, presence of train), discriminate among the auditory signals by varying their intensity, pitch, or harmonics. The number of distinct signals should not exceed four.

6.3.5 User Control and Adjustment

Recommendation 6-18: Complex information and control interactions should not be designed for use in a moving vehicle

Systems should limit or restrict manual inputs by the driver when the vehicle is moving [Also see: Recommendation 4-16].

Rationale

Lengthy task operations or complex control interactions will divert the driver's attention away from the roadway and should not occur when the vehicle is in motion. One way to accomplish this is to lock out access to complex task interactions if the vehicle is moving. If a task is interrupted before it is completed (driver initiates a task when the vehicle is not moving but subsequently starts driving), the system should enable the driver to resume the task at the point where he/she was interrupted once conditions allow. This guideline does not necessarily apply to speech-based interactions, only in situations where the driver is required to provide manual control inputs with high levels of visual demand. In general, drivers should not be allowed to conduct a task in a moving vehicle if the time required to execute the task in a static environment exceeds 15 seconds (SAE, 2004).

Recommendation 6-19: If multiple input or adjustment controls are present, design the controls so drivers can easily differentiate among the controls and their functions

Rationale

Drivers can locate desired controls more quickly if they are coded in terms of their shape, size, color, or location. Searching and reaching for controls can be distraction hazards, particularly in a moving vehicle. Coding controls will enable drivers to minimize eyes-off-road time when accessing and making control adjustments.

6.3.6 Location of Controls

Recommendation 6-20: Locate system controls within the driver's reach, with the most frequently used or accessed controls closer to the driver's line of sight and reach

Rationale

Minimizing the time it takes for drivers to access and manipulate controls will help to reduce the time required to make control adjustments and minimize driver eyes-off-road time. Interested readers should consult SAE J287 (Society of Automotive Engineers, 1993) for specifications relating to driver reach envelopes.

Recommendation 6-21: Match the type of control used to the types and levels of functions to be controlled

Controls should be designed to be operated with one hand, and system feedback to control inputs should be immediate (within 250 ms) and perceptible.

Rationale

Abundant literature exists for detailing specifications for control designs. Interested readers may consult sources, such as Sanders and McCormick (1993) or Department of Defense (DoD) Military Standards—1472D (U.S. Department of Defense, 1989) for additional details. Drivers must be able to dedicate one hand to steering the vehicle, and systems should enable drivers to interact with the control in a manner that is consistent with this requirement. Controls should provide clear and immediate feedback (tactile, force, tones, etc.); delays can cause ambiguity and may result in repeated inputs. If a delay in responding exists due to system processing time, then a message or indication should be provided to the driver indicating that the input has been received and that the system is processing the request.

6.3.7 Operational Issues Related to In-Vehicle Systems

Recommendation 6-22: At actively controlled crossings with gates, in-vehicle warnings should be timed (coordinated) with the activation of the crossing gates or other active warning devices

The system should activate and begin issuing warnings when the external crossing treatments activate (e.g., gates start to lower) and subsequently end when the active crossing elements start to cycle off (e.g., gates start to rise). In practice, systems should have a maximum of 2 seconds release time. Greater delays may run the risk of reducing perceived system reliance [Also see: Recommendation 4-25].

Rationale

Recommendation 4-25 addresses the timing relationship of in-vehicle and external displays, and it indicates that simultaneous presentation is not optimal for all situations. However, where there is a simple, unambiguous warning, or regulatory display to which drivers must respond, such as gate activation, timing consistency with the identical in-vehicle message is desirable. Warnings should be consistent with driver expectations and highway signing and controls, and minimize behavioral differences in equipped versus nonequipped vehicles when approaching an HRI. Most vehicles equipped with an in-vehicle warning system may stop (or slow) in response to a warning message (e.g., train approaching); however, these types of actions may not be expected or understood by surrounding drivers who did not receive the message. This also applies to passive crossings. In-vehicle warnings should be designed to supplement existing HRI warning systems available in the external environment (both passive and active treatments). The information provided by the display should agree with available TCDs that drivers are likely to encounter.

Recommendation 6-23: Provide system compatibility and integration

Avoid use of unique, stand-alone systems to deliver train arrival or presence information at HRIs. Use integrated systems where feasible. When an in-vehicle system includes multiple integrated functions, the system should have one common and consistent interface design (e.g., menus, formats, colors). All in-vehicle display messages (including auditory messages) must be coordinated. If the display is to be shared between different systems, a prioritization scheme must be implemented. (Time critical information should be presented first.) Information on HRI status should be communicated to drivers in a consistent and standardized manner, regardless of manufacturer or geographic location within the United States.

Rationale

This recommendation addresses two basic issues: (1) compatibility across systems and (2) integration of systems. Systems developed by different manufacturers should be functionally similar and operate a manner that is consistent with drivers' expectations. Drivers traveling across the country (or within a State or region) should have the same general experience when they encounter an HRI, and drivers may come to expect consistent information at all HRIs. To the extent possible, the HRI function should be integrated within available ITS and in-vehicle systems; this limits the number of displays and systems (particularly in the vehicle), creates consistency, provides value added to existing systems, and presents the appearance of a seamless system to the user. Integrated systems may also allow for prioritization of messages in situations where multiple warnings or system messages are competing for driver attention. HRI messages should be prioritized within the context of the complete driver information system, and messages should be presented serially.

SAE's Safety and Human Factors Committee is a key source for emerging guidance on ITS integration issues. It has issued recent documents for in-vehicle message priority (J2395_200202), navigation and route guidance function accessibility while driving (J2364_200408), a means for calculation of the time to complete various in-vehicle navigation and route guidance tasks (J2365_200205), and is currently developing guidance for integration of ITS in-vehicle user interfaces and ITS display legibility. The committee has also issued guidance for forward collision warning systems (J2400_200308) and adaptive cruise control (J2399_200312) and is developing guidance for lane change collision avoidance systems. While these warning systems are not directly relevant to HRI applications, they are useful for two reasons. First, they provide good illustrations of the kinds of considerations that should go into in-vehicle warnings. Second, these types of warnings, together with the navigation and route guidance tasks, indicate the types of other ITS functions with which the HRI service must be integrated. Further information is available on the SAE Web site (www.sae.org).

Recommendation 6-24: Indicate system status

Provide an indication that the in-vehicle system is operating and functioning normally. If the system functions at limited sites (or under specific conditions), include some means for communicating this information to drivers. Drivers must be able to know when their system is functioning and when the system is not active.

Rationale

Some means to communicate warning system status is needed; drivers should not think they are getting a warning when they are not. Section 3.1.5 describes an example with the school bus in-vehicle signing system (SRF Consulting Group, 1998). This system used a blue LED to indicate normal operation (system status). The blue LED also flashed when the vehicle was in the presence of a transmitter signal (not all HRIs were equipped).

Recommendation 6-25: Tailor information presented within the vehicle to match the driver's specific situation and needs (e.g., approaching an HRI, waiting at an HRI, EMS personnel)

Rationale

Motorists may have different information needs based on their familiarity with the HRI, distance from the HRI, and type of vehicle. Drivers waiting at the HRI for the tracks to clear may benefit from knowledge about estimated train crossing time and how long the train has been moving through the HRI. Approaching drivers, upstream of the HRI, may desire information about alternate routes. Differences may also exist in the amount and type of advance warning and level of accuracy needed by users (e.g., EMS, police, truck drivers, bus drivers). Systems should provide only relevant information in suitable forms to support driver decisionmaking. Information that is tailored for each vehicle type or for each driver may be much more specific and more useful than generic information. Additionally, presenting tailored information has the potential to reduce the number of annoying or distracting irrelevant messages that each driver receives.

Recommendation 6-26: Evaluate the potential effects of behavioral adaptation for new in-vehicle systems

Before widespread implementation, new ITS systems should be tested extensively. The test plan should include an evaluation of changes in driving behavior that may occur as a result of using the new technology. Four particularly important periods for behavioral testing should be considered: (1) before being exposed to the system, (2) while learning to use the system, (3) shortly after learning to use the system, and (4) after long-term use of the system.

Rationale

Motorists may adapt to new technologies in ways not envisioned by system designers. These changes can be positive, negative, or neutral with respect to their effect on safety; therefore, it is important to evaluate these behavior changes before widespread deployment of any system. To assess behavioral changes in driving behavior, it is desirable to have baseline measurements of driving behavior before the technology has been introduced. Different behavioral adaptations can occur after short- and long-term experience with the technology. Measurements taken during the learning phase may reveal adaptations in driving behavior due to new physical or cognitive demands imposed by the technology, while later adaptations may reveal that the technology is no longer used due to factors such as annoyance. In the long term, driving behavior may even change to become so overly dependent on the technology that any initial safety benefits are neutralized.

7. Displays for Pedestrians

7.1 Background

This chapter provides guidance on infrastructure-based displays for pedestrians at the HRI. Although some ITS envisioned for pedestrians, particularly those who have a visual or auditory impairment, may include a small personal display device that is carried, the research team has restricted the guidance here to infrastructure-based solutions because these are more likely to be widely implemented in the immediate future. As in Chapters 5 and 6, the recommendations given here are general and may apply to several different ITS applications. Chapter 8 (Warnings about Train Arrival) and Chapter 11 (Light Rail Transit) give other recommendations concerning systems for pedestrians that are related to specific applications.

Some HRIs, particularly those involving light rail, accommodate a large volume of pedestrians, making crosswalk safety of particular concern at these locations. For pedestrians, HRIs differ from highway-highway intersections in terms of the right-of-way sharing behavior required. Unlike crosswalks where cross traffic (motor vehicles) may be required to yield, pedestrian way-rail intersections never require that trains yield to pedestrians. Pedestrians are generally successful at avoiding being struck by trains, but when they are struck the result is often fatal. During a 3-year period (2000–2002), a total of 243 incidents (including 150 fatalities) occurred in which trains struck pedestrians at HRIs. This represents 3 percent of the total 7,694 highway-rail crossing incidents that involved a train striking a roadway user during this period (FRA, 2002, 2003, 2004). These statistics do not include incidents in which a roadway user struck a train, trespassing incidents which occurred away from the HRI, or evident suicides.

The characteristics and needs of pedestrians differ from those of motorists. Pedestrians travel more slowly and may require more time than motor vehicles to clear the HRI when there are multiple tracks. Pedestrians are less restricted, and more variable in their movements than motor vehicles. They may approach the HRI from several different angles, or they may choose to cross at undesignated locations when an opportunity exists to shorten the distance to their destination. Pedestrians may also find it easier than motorists to circumvent active controls, such as gate arms and swing gates. On the other hand, pedestrians may be able to react later than motorists to an approaching train and still avoid being struck. Because the inertia of a pedestrian is low compared with that of a motor vehicle, pedestrians are able to stop more quickly and initiate movement more quickly. If they are aware of the hazard, pedestrians are usually able to step out of the dynamic envelope of an approaching train in time. When approaching the HRI, the pedestrian's go or no-go decision point may be quite close to the tracks, where sight distances in each direction are often better than those available to approaching motorists at their decision point some distance upstream from the HRI.

Although an approaching train with its visual and auditory properties is a more powerful stimulus for pedestrians than for motorists who are somewhat insulated inside their vehicles, this stimulus is so powerful that sometimes it may mask a second train approaching the HRI in close proximity to the first. MTWs targeted to pedestrians may improve safety at HRIs that have frequent multiple train events (see Chapter 8). In an urban environment, the sounds of traffic and other noises may mask the sounds of an approaching train. This concern is especially relevant for light rail vehicles (LRVs) that tend to be much quieter than conventional trains. Pedestrians who have a visual, auditory, motor, or cognitive disability may be particularly at risk.

According to Siques (2001), there are

> …four key factors that enable pedestrians to walk through a grade crossing safely: (1) pedestrian awareness of the crossing, which can be enhanced by passive signs and tactile warnings; (2) the pedestrian path across the tracks, which is subject to pedestrian channelization and positive control devices; (3) pedestrian awareness of and ability to see an approaching light rail vehicle (LRV), which depends on pedestrian sight distance at the crossing and can be improved through active warning devices; and (4) pedestrian understanding of the potential hazards at grade crossing, which requires public outreach and education.

ITS-based systems may contribute especially to Factors 1, 3, and 4 by providing specific warnings to pedestrians about characteristics of the crossing and about train arrival. By automatically detecting pedestrians approaching the HRI, pedestrians who are trespassing on the rail system right-of-way near the HRI, and pedestrians crossing the HRI in violation of active warning devices, it is possible to deliver specific warnings tailored to these groups. However, conventional technologies, such as channelization devices and other positive control devices, can also play an important role in pedestrian safety at the HRI, and these should be considered along with more technologically sophisticated devices.

7.2 Key Human Factors Issues and Need for Guidance

7.2.1 Issue: Locating Pedestrian Displays for Effectiveness

Many general issues related to locating roadside displays (see Chapter 5) apply to pedestrian displays as well. Other issues are specific to locating pedestrian displays. Depending on the environment around the HRI, the pedestrian channelization treatments (if any) that are present, and the direction of pedestrian destinations downstream of the HRI, pedestrians may be oriented in several different directions as they approach the HRI. Pedestrians who approach within a crowd may be engaged in conversation or may be preoccupied with monitoring the movements of other pedestrians around them and may not scan for visual displays before stepping into the HRI. Shorter pedestrians and wheelchair users may have reduced sight distances due to people around them and often may emerge from a crowd at the HRI, without having been able to see any displays as they approached. Advertising signs, traffic signs, and other visual clutter near or beyond the HRI may reduce the conspicuity of visual displays for all pedestrians. In these situations, alternate mounting locations or conspicuity enhancements may be possible. Displays for pedestrians, however, should not be conspicuous to motorists who may be distracted by them as they approach and cross the HRI.

7.2.2 Issue: Serving Pedestrians Who Have Sensory, Cognitive, or Motor Impairments

Human factors guidance is needed to understand how ITS technologies may benefit pedestrians who have disabilities. For example, persons who are blind have several basic informational needs related to crossing the HRI that are similar to the problems encountered when crossing a roadway (Barlow, Bentzen, & Tabor, 2003). Some of these include identifying the HRI, detecting the edge of the HRI and the crosswalk, understanding the geometry of the HRI (including the number of tracks, angle of tracks relative to the crosswalk, and direction of destination), knowing when it is safe to cross, knowing if they are maintaining a straight path across the tracks, understanding when a train is approaching (perhaps a relatively quiet LRV), knowing when more than one train is approaching, and knowing where it is safe to stand while trains pass by. Persons who have auditory or cognitive impairments will have similar informational needs related to safely crossing the HRI. All of these needs may be considered as opportunities for new technologies. Determining the best ways to meet these needs will require further research.

7.2.3 Issue: Benefits of Enhanced Information about Train Arrival

Intelligent systems may be able to provide pedestrians with specific temporal information, such as the time until train arrival or the amount of safe time remaining for crossing. It is not known whether such information would have safety benefits or be detrimental. For pedestrian crossings at signalized roadway intersections, countdown pedestrian signals are now an option in the MUTCD (Section 4E.07). These displays supplement the standard pedestrian signal display with a countdown timer that shows the number of seconds remaining in the pedestrian change interval (before the steady DON'T WALK phase, a few seconds before the release of conflicting traffic). Several research studies on countdown pedestrian signals (e.g., Huang & Zegeer, 2000; DKS Associates, 2001; Botha et al., 2002) have indicated that when pedestrians receive this temporal information, a higher rate of successful crossings occurs. Pedestrians are less likely to be present in a crossing when the pedestrian change interval ends and so are less exposed to conflicting traffic. At the same time, however, an increase in noncompliance also occurs, meaning that more people begin crossing after the clearance interval (flashing hand icon) appears. Nonetheless, the explicit temporal information apparently allows these pedestrians to better time their crossings, and the outcomes are better. The potential benefits or risks of temporal information for pedestrians at HRIs are not known. The guidance of this chapter does not provide a recommendation for the use of countdowns given the absence of knowledge about this. Based on the experience at signalized roadway intersections, however, improved pedestrian behavior may occur with more specific information, and this bears investigation.

7.2.4 Issue: Intelligent Recognition of Pedestrians and Prediction of Their Behavior

Warning and regulatory messages for pedestrians are typically based on the status of the HRI and the proximity of trains. The message is not related to the pedestrian's behavior. If a pedestrian is in a particularly dangerous situation, however, it may be desirable to provide a more urgent warning. Emerging technologies for pedestrian detection provide the opportunity for intelligent recognition and communications. ITS approaches based on pedestrian detection are currently being explored for roadway applications. In these roadway situations, when a potentially hazardous situation is detected, the warning message may be presented to the pedestrian or to the vehicle driver, or there may be a direct change in assigned right-of-way (e.g., extend the red signal phase of conflicting traffic). These latter options are generally not feasible for the HRI. If pedestrians are detected to be in some dangerous situation, a warning must be directed toward the errant pedestrians themselves. Potential sensing technologies include infrared and microwave sensing, pressure sensitive surfaces, and real-time video image processing. Potentially, various sensing technologies could recognize such factors as pedestrian presence, pedestrian location relative to crossing features (e.g., rails), pedestrian speed and direction of travel, anticipated speed and direction of travel, and special user features (e.g., wheel chairs, children). Human factors questions include the determination of those situations for which pedestrian sensing and warning may have meaningful potential safety benefits, the behavioral criteria for defining risky situations, and the types of messages and displays that will quickly generate the desired pedestrian response.

7.3 Recommendations

Table 7 groups recommendations about displays for pedestrians under four topics. For each topic, the individual recommendation statements are given.

Table 7. Recommendations for pedestrian displays

Positioning the display
1. Install visual displays in locations that are consistent with pedestrians’ expectations, close to the intended crosswalk, and within a 20-degree cone of the forward line of sight.
2. Ensure that warning displays are configured so that they are conspicuous for pedestrians who are in the process of crossing the tracks when a train warning is issued, as well as for pedestrians who are approaching the HRI.
3. Separate messages for motorist from messages for pedestrians.
Accessibility of the warning
4. Consider multiple modes of display when providing warnings or other information to pedestrians at the HRI.
5. Include pedestrians who have disabilities in the design and testing process for new display features.
Directed warnings
6. Consider providing a targeted “last chance” warning system for pedestrians who are in immediate danger.
Use of conventional pedestrian control devices
7. ITS displays for pedestrians should be used in conjunction with positive control devices, such as gates and barriers.

7.3.1 Positioning the Display

Recommendation 7-1: Install visual displays in locations that are consistent with pedestrians’ expectations, close to the intended crosswalk, and within a 20-degree cone of the forward line of sight

Design and locate displays for pedestrians who approach the HRI from various directions and for those whose attention may be oriented to different destinations downstream of the HRI. For displays mounted on the near side of the HRI, ensure that pedestrian displays are conspicuous and legible (or audible) to pedestrians with various eye (and ear) heights (from children and wheel-chair users to tall adults).

Rationale

Korve (1999) and Siques (2001) have recommended placing passive signs low, below 6.5 feet so as to be within pedestrians’ cone of vision while walking, but outside the intended pathway so that pedestrians do not accidentally bump into them. This recommendation also applies to active ITS-based displays at the HRI that are intended for pedestrians. According to the MUTCD (Federal Highway Administration, 2003), standard pedestrian signal heads (which are normally viewed from across an intersection) should be mounted somewhat higher, with the bottom of the signal housing at a minimum of 7 feet. Other considerations include the potential for injury from the low mounted displays and the potential for vandalism.

Differences in pedestrians' eye heights may significantly affect the viewing angle for displays located close to pedestrians on the near side of the HRI. Pedestrians with unusually high or low eye heights may fail to notice visual displays mounted close to them if the viewing angle is too large. Pedestrians with lower eye (ear) heights may also have more difficulty seeing or hearing displays due to the screening effects of crowds.

Recommendation 7-2: Ensure that warning displays are configured so that they are conspicuous for pedestrians who are in the process of crossing the tracks when a train warning is issued, as well as for pedestrians who are approaching the HRI

[Also see: Recommendations 4-1, 8-10, 8-22]

Rationale

Displays located on the near side of the HRI and oriented for pedestrians approaching the HRI may not be visible (or audible) once the pedestrian is in the middle of the HRI. Displays should be effective at all positions in the crosswalk.

Recommendation 7-3: Separate messages for motorists from messages for pedestrians

Messages should be targeted exclusively to the intended audience. For example, an auditory speech warning directed to pedestrians should be configured so that the warning is clearly audible to pedestrians but does not confuse or distract motorists. Warnings for pedestrians and motorists should be coordinated so that they do not interfere with one another (e.g., warning bells masking a pedestrian speech warning). Visual displays for pedestrians should be positioned so that they do not distract motorists.

Rationale

Roadway users require meaningful and consistent information. The intended audience of train arrival messages must be clear to roadway users. This is especially important if different timing is used or if different message content is delivered to each audience [Also see: Recommendations 4-9, 4-20, 6-25].

7.3.2 Accessibility of the Warning

Recommendation 7-4: Consider multiple modes of display when providing warnings or other information to pedestrians at the HRI

These could include visual, auditory, and tactile displays. Information should be redundant and complementary across modes so that each one adequately expresses its message independently of the others to better serve a wide variety of pedestrians who may have visual, auditory, cognitive, or motor impairments. (This includes needs for displays with a lower visual angle or large size features.) Consider placing the display closer, to be read by pedestrians on the same side of the tracks. Also consider using auditory and tactile displays [Also see: Recommendations 4-21, 4-22, 4-23, 11-9].

Rationale

Single-modality displays may not adequately communicate the warning message to pedestrians who have sensory disabilities. Using combined auditory and visual cues reduces this risk. The use of multiple modalities will also make the warning more conspicuous to pedestrians who do not have any disability, including those who may be distracted by secondary tasks (such as talking on a cell phone) or other environmental stimuli, such as roadway traffic, advertising displays, and other people. In compliance with ADA requirements, the U.S. Access Board develops accessibility guidelines for designers of government facilities and places of public accommodation. Designers of pedestrian access routes should consult the *Draft Guidelines for Public Rights of Way* (U.S. Access Board, 2002). Although this document contains only a few guidelines which directly address the HRI (Surface Gaps at Rail Crossings—1103.7 and Detectable Warnings—1103.7.1), the general principles described in other sections may also be helpful to designers of pedestrian access routes which cross the HRI.

Recommendation 7-5: Include pedestrians who have disabilities in the design and testing process for new display features

[Also see: Recommendations 4-21 through 4-23]

Rationale

To clearly understand pedestrians' needs at the HRI, it is necessary to engage them in the design process. Initially, this may be done through observational study, focus groups, individual interviews, or other behavioral research techniques. From these data, a set of evidence-based user requirements can be written to represent pedestrians' real needs. Persons who have particular disabilities may have somewhat different strategies and behaviors for navigating through the HRI than other pedestrians; therefore it is important to include them in user research so that their unique needs will be considered in user requirements documents. As development of the ITS system proceeds, concepts and prototypes may be tested with pedestrians as part of an iterative design process. Pedestrians who have disabilities should also be included at these stages of development because they may uncover safety or usability issues that would be missed by other users of the system.

7.3.3 Directed Warnings

Recommendation 7-6: Consider providing a targeted "last chance" warning system for pedestrians who are in immediate danger

Consider providing an additional warning to pedestrians who remain between the tracks or within the train dynamic envelope after standard active warning devices have been activated. Train arrival warnings should be provided to pedestrians who have already begun crossing the tracks. The warning should indicate that a train is approaching and the appropriate action to take. An automated detection system can be used to determine whether a pedestrian is in the path of an oncoming train. Some visual detection systems can even detect speed and direction of movement, which may allow the system to determine whether the pedestrian is moving to clear the dynamic envelope. If it is determined that a pedestrian is in danger of being struck, a targeted warning may be the last chance to motivate the pedestrian to clear the HRI [Also see: Recommendations 4-13, 11-4].

Rationale

Pedestrians move more slowly than vehicles and therefore may take longer to clear the HRI. This is especially relevant at wide HRIs with multiple tracks. Automated detection systems have been used at HRIs for automated enforcement and to detect blocked HRIs (but have yet to be used to detect pedestrians who are too close to the tracks). Although automated enforcement of pedestrian crossings is not feasible, the existence of targeted warnings may serve to deter unsafe crossings or may alert pedestrians who, although not standing inside the tracks, may be inside the train's dynamic envelope and unaware of the hazard. Some visual detection systems can even detect speed and direction of movement, which may allow the system to determine whether the pedestrian is moving to clear the dynamic envelope. The system should be designed in such a way as to prevent or discourage intentional system activation.

7.3.4 Use of Conventional Pedestrian Control Treatments

Recommendation 7-7: ITS displays for pedestrians should be used in conjunction with positive control devices, such as gates and barriers

[Also see: Recommendation 11-1]

Rationale

Channelization of pedestrian traffic by fences, barriers, gates, and other non-ITS measures is effective to control pedestrians' orientation with respect to the HRI, approaching trains, and warning displays (Siques, 2001, 2002). These devices reduce the variability among pedestrians' lines of sight, focusing attention in the direction of the hazard and active warning devices. Automatic closing gates provide a cue that the train is approaching and a physical barrier to deter pedestrians from entering the HRI. Gates should open automatically when the tracks are clear, and they should open away from the tracks, providing an obvious, easy means of escape for pedestrians who get trapped inside the HRI.

Part IV: Human Factors Considerations for Specific Applications

8. Warnings about Train Arrival

8.1 Background

This chapter provides human factors guidance concerning the use of ITS technology to warn roadway users about train arrival at HRIs, including the special case of warnings about multiple trains approaching. The specific issues discussed and the guidance given are restricted to warnings about train arrival, even though ITS applications that deliver such warnings may provide road users with additional information as well. Chapter 9 discusses alerts about the presence and status of HRIs and messages about alternate routing. Chapter 10 gives guidance concerning enforcement and control, and Chapter 11 presents guidance that is especially relevant for LRT applications.

Typical active warning devices (lights and gates) present only a single, general message to roadway users about train arrival at the HRI: a train is somewhere in proximity to the HRI. However, with emerging ITS technology it is feasible to monitor train movements and predict train arrival times, making it possible to inform roadway users with more specific messages about the number of trains approaching, speed, position, heading, and time required for trains to clear the HRI. With the availability of this new information comes several human factors questions about the best ways to provide such information and how such information will affect driver and pedestrian behavior. For example, real-time, accurate train status information provided to motorists and pedestrians waiting at the track might reduce anxiety about long waits and might lower the risk of drivers violating active controls (driving around gates), thereby reducing the frequency and severity of vehicle-train crashes. On the other hand, if such information is unreliable or presented in the wrong way, it could encourage risky behaviors, thereby reducing or even eliminating net safety benefits.[7]

8.2 Key Human Factors Issues and Need for Guidance

8.2.1 Issue: Information to Communicate about Train Arrival

Train arrival warnings should support driver information needs and decisionmaking. Motorists approaching an HRI need to be able to orient to approaching trains or trains in the HRI, so that they can plan and execute appropriate behaviors. Various types of information may be communicated, including data addressing train dynamics, train characteristics, and predictive and historical information, as well as information detailing HRI site characteristics. Specific information elements may include number of trains near HRI; current train position, location, and presence (train approaching or occupying the HRI), estimated time of arrival at the HRI:

[7] Several reviewers expressed concerns about the reliability of train arrival estimates. One noted that "the arrival time accuracy is considerably degraded with distance from the crossing, particularly with light rail or commuter trains that can quickly accelerate or decelerate. This time information needs to be considered in providing rerouting information to drivers." Another noted the some collisions are related to "non-standard movement" around a crossing (e.g., "stopping without being on the crossing or moving back and forth to pick up freight cars"). Another emphasized the need for better communications between the train and the crossing, stating that "while constant time warnings have improved these communications at crossings with active warning systems, they are not sensitive to variations in train movements. Too much attention, in some cases, is being given to automating all of the systems, and too little to the combination of manual and automated systems" (e.g., where switching movements take place near a crossing).

train speed; train direction; train length; train type (e.g., freight, passenger, high-speed); estimated train crossing time (duration of the train event/blockage); how long the train has been moving through the HRI; and alternate route (closest grade separation) among others. Human factors concerns and issues relating to information about train arrival address the extent to which motorists are provided with relevant, consistent, and meaningful information to support their decisionmaking. The type of information, amount of information, and relevance and meaningfulness of the information should be consistent with driver needs and tasks. Providing too much information, or irrelevant information, may overwhelm drivers, slow information processing, and/or contribute to distraction. The relative importance of information may also vary as a function of the driver's location relative to the HRI; motorists at the HRI may desire different information than those approaching the HRI. Those waiting at the HRI for a train to pass may also have more time and opportunity to process lengthy and detailed messages compared with those in transit. System designers should construct consistent standardized messages that support the needs of drivers approaching or waiting at an HRI, in a manner that allows drivers to quickly extract and understand important information about train arrival.

8.2.2 Issue: Signal Characteristics (How to Communicate)

The means through which train arrival information is communicated to drivers can play a significant role in how drivers interpreted, understood, and used that information. ITS applications at HRIs have employed a number of methods to transmit information to drivers, including in-vehicle and external roadside systems. A review of operational tests (Chapter 3) found a range of different designs and interfaces to provide train arrival information, including CMSs, HAR, fixed signing with dynamic elements, and stand-alone in-vehicle audio-visual displays, as well as information kiosks, integration with in-vehicle navigation systems, personal digital assistants (PDAs), cell phones, and Internet. Because driving is a complex task requiring significant mental and physical demands, the physical properties of the alerts, warnings, and messages about train arrival must be consistent with the environment and must stand out among other signals (and noise) to capture driver attention without being annoying.

8.2.3 Issue: Coordination with External Controls and Traffic Management Centers

New train arrival warnings must be compatible and consistent with existing traffic control systems and should take into consideration that not all drivers may have access to advance train information (particularly if it is provided in the vehicle). If ITS-equipped drivers, for example, receive advance knowledge of an approaching train (via an in-vehicle display), their behavior may not be predictable to surrounding traffic. Equipped drivers may stop their vehicle at the HRI before activation of any available active controls (gates), and this may result in increased vehicle-to-vehicle collisions. Another important feature of ITS applications, such as train arrival warnings, is the ability to coordinate and share information with Traffic Management Centers. These centers in turn can control signal phasing, disseminate train movement information, and coordinate with emergency services.

8.2.4 Issue: Signal Conspicuity

The ability to capture the roadway user's attention is a critical requirement for all types of train arrival warnings, including MTWs. This issue is important for in-vehicle displays and roadside displays.

Drivers may not notice train arrival warnings presented through in-vehicle visual displays if the warnings are not positioned close to the cone of vision around the driver's line of sight. For in-vehicle displays mounted on the dashboard, supplemental auditory signals or dynamic visual components (e.g., flashing light) may be needed to direct the driver's attention. Auditory signals in vehicles may not be conspicuous if they do not adapt to changes in the ambient noise level.

Train arrival warnings presented on roadside displays share many of the same conspicuity issues as other signage. For example, unfavorable lighting or weather-related conditions may reduce visibility. Conspicuity of roadway displays depends on many features of the display, such as size and location relative to the driver's line of sight, and on contextual factors, such as the number of other signs present and the visual complexity of the background.

Current MTWs use visual displays external to the vehicle (roadway signs). For roadway displays, the requirements related to the conspicuity of the MTW may be somewhat unique. For displays intended for vehicle traffic, the display must be visible to, and capture the attention of, the motorist in the vehicle immediately in front of the lowered gate. This is unlike the case of crossing lights and gates, which must be visible on the approach to the HRI; they must be within the cone of vision around the driver line of sight at some distance from the tracks. This is also unlike the case of intersection traffic signals, even though the driver may be stopped at the intersection. At a roadway-roadway intersection, the driver must monitor the traffic signal to know when to proceed. The driver stopped at a lowered railroad crossing gate will not be monitoring any overhead or roadside signals. Rather, his or her attention is likely to be fixed on the gate and the passing train, with the intent to proceed as soon as the track is perceived to be clear. The MTW must counter this intent even though the driver does not have attention directed at the display. For a driver stopped at the tracks, the viewing angle for displays mounted on mast arms over the track or at the roadside may be oblique and outside of the cone of vision around the likely line of sight. Therefore, it is essential that some action be taken to enhance the ability of the display to attract driver attention, through enhanced target value or placement or acoustic signals or other means. Current standards and guidelines do not address this problem.

Similar problems may arise for pedestrian applications. In the absence of a pedestrian gate, the likelihood of proceeding across the tracks without noticing a train arrival warning or MTW may be even greater for pedestrians than for vehicles. In addition, ambient noise levels may be high or highly variable for pedestrians near the track due to motor vehicle traffic or nearby trains; therefore, auditory warnings must be designed carefully to retain their conspicuity under all noise conditions likely to be encountered.

8.2.5 Issue: Message Timing

Timing of train arrival messages is a concern for both triggering the onset of ITS alerts and warnings, and for their deactivation relevant to external systems. Although this issue is particularly relevant for active crossings, it also applies to the timing of information communicated by ITS at passive crossings.

Information on train arrival must be presented far enough ahead of the hazard so that the driver has time to process the information, make a decision, and take the appropriate action. The purpose of the alert or warning will determine how far in advance of the HRI the message should be communicated. Information about train arrival that is meant to guide drivers to alternative routes would likely be presented further upstream from the HRI than information meant to warn drivers to yield to an approaching train. At various time points during the driver's approach to the HRI, as the driver's information handling capability changes, it may be appropriate to present messages with different content and format.

Other message timing concerns exist for MTWs. Current MTWs use dynamic displays with sequential phases. It may take a significant period of time (e.g., 9 seconds for the Maryland MTA implementation) to cycle through the entire message. The driver at risk for a second train collision is the impatient driver who proceeds without adequate search and who may circumvent gates. Therefore, the multiple train message must have impact on behavior quickly. The display needs to be activated with minimal or no delay after the first train passes. The initial phase of the display must inhibit the driver's actions. The driver should not be expected to patiently wait for the entire sequence in order to get the meaning. Existing displays do not appear to have been evaluated from this perspective.

8.2.6 Issue: Message Comprehension

Train arrival warnings (and MTWs) should convey the specific idea that a train may be coming (or another train coming), that may not be visible yet, and a collision threat exists if the driver proceeds. No existing standard or common practice for this type of display is currently in place. It may be difficult to convey this idea quickly, reliably, and legibly. If the sign only conveys the idea of caution, some benefit may exist, but the promotion of desired behaviors will not be optimal. The display therefore needs to be specifically, reliably, and quickly understood by the full range of users. If combinations of graphic and/or text message elements are required to convey this message, visual complexity and clutter may compromise comprehension.

8.3 Recommendations for Train Arrival Warnings

Table 8 groups recommendations for train arrival warnings under four topics. Each topic includes individual recommendation statements.

8.3.1 Information Provision (What to Communicate)

Recommendation 8-1: Display train-related information only if it fulfills a need

Define the specific driver information need(s) the train arrival display is intended to meet. Limit information to that which fulfills the need. Avoid providing related information in multiple forms; use a single type of metric in a simple form (e.g., time, distance). Generally, simple statements regarding the appropriate behavior are preferable to descriptive information about train arrival, especially quantitative information [Also see: Recommendations 4-9, 8-4].

Table 8. Recommendations for warnings about train arrival

Information provision (what to communicate)
1. Display train-related information only if it fulfills a need.
2. Limit the amount of information presented.
3. Issue alerts about the presence of HRIs and warnings about the presence of trains.
4. Present integrated, directly usable information.
5. Design messages based upon information handling zones.
6. Provide standardized message content on CMS at the HRI.
7. Provide cues as to the direction of approaching trains.
8. Provide a release indication.
Signal characteristics (how to communicate)
9. Use CMS as a primary means to communicate HRI status.
10. Consider conspicuity enhancements for visual displays.
11. Avoid temporal countdown displays for motorists.
12. Provide accurate and reliable information.
13. Minimize nuisance warnings for drivers not in potential conflict.
Timing of signals for train arrival warnings
14. Issue warnings throughout the entire duration of the train event, but provide a way to reduce the nuisance potential of the warning.
15. Inform roadway users at HRIs where extended advance warning times are used.
Coordination with external controls
16. Coordinate ITS warnings and non-ITS traffic control devices.

Rationale

ITS capabilities may make it possible to provide a wide range of detailed information regarding train arrival. For example, there may be access to data on train speed, distance, time to arrival, time to gate activation, train length, time to clear, train direction, multiple trains, unusual signal timing (e.g., longer than 20 seconds constant warning time (CWT)), and so forth. This may make it tempting to provide road users with more information or more precise information. More, however, is not necessarily better. The driver should not receive too much information, irrelevant information, or information that promotes inappropriate driver actions. The information displayed should be based on driver information needs. Even if road users have a desire for certain types of information, presentation should be limited to needed information in its most effective form. Section 1A.02 of the MUTCD (Federal Highway Administration, 2003) specifies requirements for effective TCDs. Among these are fulfilling a need, conveying a clear simple meaning, and giving adequate time for proper response. Therefore, the display should select among potential information based on the specific scenario, road user information requirements, and the most appropriate information given the time and place of the message presentation. Generally, road users will not have a good sense of quantitative aspects. Is a 70-mph train faster than normal? Is a 20-second train arrival time a comfortable margin for clearing an HRI? Therefore, qualitative statements (high-speed train) or specification of driver response (stop, do not enter) are generally preferable. Some messages (e.g., time for train to clear) may exists where there may be benefits to quantitative information, but careful consideration should occur whether drivers will actually use such information.

Recommendation 8-2: Limit the amount of information presented

Systems should provide drivers with the necessary information to make an informed, safe decision (e.g., cross the tracks, wait, re-route) while staying within the limits of the amount of information that the driver can process [Also see: Recommendations 4-11, 4-26, 5-2].

Rationale

Providing large amounts of information (or irrelevant information) may increase the time required to process system messages and may confuse or distract drivers. Distraction from reading or glancing at visual displays while driving is a particular concern. Lengthy text messages or visual displays may overload drivers or require them to take their eyes off the road for a significant length of time. Research on in-vehicle ATIS indicates that drivers generally only use a limited amount of information (two to three items) to support their decisionmaking (Lerner & Steinberg, 2000; Llaneras, Lerner, Huey, & Bensur, 2000). Prioritize the information and present only important items; primary items of interest will likely vary depending on the context and drivers' specific situation. Consider limiting the amount and type of information provided to drivers to a few key items. The specific type and amount of information presented also depends on the form of the message (e.g., visual display, auditory display), as well as the context (e.g., in-vehicle, Internet, kiosk). Properly constructed auditory messages can be less demanding to process than complex visual displays.

Recommendation 8-3: Issue alerts about the presence of HRIs and warnings about the presence of trains

Drivers approaching an HRI should be provided with two general types of information, provided that the information is reliable: (1) an alert indicating the presence of an HRI and (2) a warning indicating that a train is present or approaching the HRI. Advanced ITS systems should support both types of advisories and warnings. The two should be clearly discernable and should reflect the urgency of the situation. While systems that only present advisories are particularly beneficial at passive crossings where drivers are responsible for detecting the presence of trains, they may have limited utility for familiar drivers.

Rationale

A two-stage warning that provides different levels of information (HRI ahead and train approaching) may facilitate driver performance by building expectation. Warnings should reflect the urgency of the situation; drivers should perceive a train approaching warning to be urgent and necessitating a fast response. Unfamiliar drivers will benefit from an advisory alerting them to the presence of an HRI. All drivers benefit from knowledge of an approaching train or train occupying the HRI. Field tests and implementations of in-vehicle signing systems have provided drivers with both types of information; however, if the information is not reliable, drivers may lose confidence in the system.

Recommendation 8-4: Present integrated, directly usable information

Providing integrated information that is meaningful to drivers supports their decisionmaking and does not require them to perform complex mental operations. Information communicated to drivers should be conveyed in a directly usable form.

Rationale

Although train speed, location, and direction information can be communicated to drivers and used to predict train arrival time at an HRI, it does not provide directly usable information (will the train be at the HRI when I get there?). Requiring drivers to integrate information elements can place an unnecessary demand on their attention. It is preferable to communicate estimated train arrival time or a directly usable, individualized message about whether (and how long) they will have to wait for the train to pass if they continue on their present route toward the HRI.

Recommendation 8-5: Design messages based upon information handling zones

Information about train arrival should be appropriate for its location with respect to information handling zones upstream of the HRI. The content, format, and complexity of the message should be suitable for the information handling zone in which it is presented. Table 9 shows desirable characteristics for messages in various information handling zones.

Table 9. Message characteristics for information handling zones

Zone	Defining Point	Message Content	Message Format	Message Complexity
Advance	Before decision sight distance	Planning, guidance information, HRI status	Unrestricted; can include text, phased messages, dynamic elements	Can be relatively complex if other roadway characteristics allow; information load as key criterion
Approach	Decision sight distance	Safety-related information	Warning format	Simple graded or temporal information OK; should not require long total glance time; eye-off-road time as key criterion
Non - recovery	Stopping sight distance	Crash avoidance specify single driver response	Urgent safety warning format, high conspicuity	Simple, immediate message; response time as key criterion
Stop Point	Gate, stop line, or other marking	Safety or informational	Warning or informational	Can be relatively complex; message duty cycle must be consistent with driver behavior

Rationale

Information should be located so that the driver receives it with enough time to respond properly and without conflicting with other task demands, but not so far in advance that it is inappropriate, ignored, or forgotten. ITS messages about train arrival should be based on an analysis of where and when the information is needed. This is true for roadside and in-vehicle displays. One convenient simplifying scheme for characterizing message locations is to view the approach to an HRI as a sequence of information handling zones. This concept was developed within the

Positive Guidance Model of Driver Behavior (e.g., Alexander & Lunenfeld, 1975; Lunenfeld & Alexander, 1990), which described five zones in relation to some highway hazard: the advance zone, approach zone, nonrecovery zone, hazard zone, and downstream zone. The concept is applied to HRI applications in the *Railroad-Highway Grade Crossing Handbook* (Tustin, Richards, McGee, & Patterson, 1986), focusing on the approach, nonrecovery, and hazard zones. For ITS considerations, the hazard zone is probably of less relevance, but the advance zone is of more relevance. The highway design concepts of stopping sight distance and decision sight distance define the zones. Where an ITS system has sufficient intelligence regarding a specific vehicle (e.g., speed, location), these zones can be defined for each driver; otherwise, they are based on assumptions about vehicle speed. Figure 15 (from Lerner et al., 2002) illustrates the information handling zones. However, the hazard zone refers to the area where there is a potential collision; for HRI applications, this usually, though not necessarily, will be the dynamic envelope around the track. For example, an analysis could focus on an active barrier that is located in advance of the track.

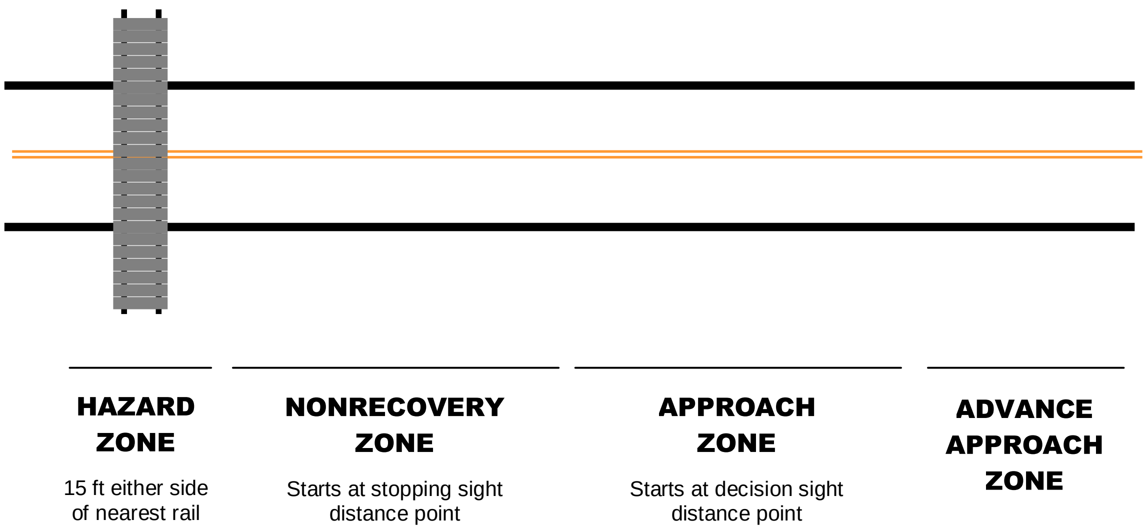

Figure 15. Information handling zones (from Lerner et al., 2002)

Brief rationale statements for the recommendations in Table 9 follow:

- *Advance zone*. The advance zone is the area sufficiently in advance of the HRI that the driver does not need to be dealing with immediate decisions and actions about speed, path, visual search, or other actions at the HRI. Therefore, few restrictions are on the type of ITS information or manner of displaying it, other than good signing or display practices that would be appropriate to any roadway application. If the message is complex, consideration should be given to driver information load requirements, including the presentation of the message with respect to other signs, ITS messages, and driving demands.
- *Approach zone*. The approach zone begins at the decision sight distance, the theoretical distance required for a driver to plan and execute safe and efficient maneuvers to unexpected or difficult-to-perceive information or events. The approach zone is where the driver formulates and begins to execute the actions needed to avoid hazards (e.g., visual search) and operate the vehicle in a controlled manner (e.g., speed adjustments,

smooth stopping). Because the driver must be planning safety-relevant actions here, ITS information in this area should be limited to safety information and be in a format that makes it clearly obvious that this is a safety message. Message content can be graded (e.g., levels of warning) or temporal (e.g., train arrival time). Because drivers must be planning and initiating a maneuver, however, the display should not require the drivers to take their attention away from the roadway, HRI, or traffic for extended periods.

- *Nonrecovery zone.* The nonrecovery zone begins at the stopping sight distance, the theoretical last moment that the driver could respond to a message and stop the vehicle before entering the hazard zone. Because drivers reaching this zone must quickly react to any potential hazard, only high-priority safety messages requiring an immediate response should be presented here. Messages must be conspicuous, simple, quickly comprehended, and indicate a clear sense of the required maneuver.
- *Stop point.* The term stop point (not a zone in the Positive Guidance model) is used here to indicate the situation where information about trains is provided to drivers who are already stopped at the HRI. Because the vehicle is stationary, concerns about driver distraction and eye-off-road time are minimal. Therefore, displays can be more complex and have longer duty cycles, if required. The message may be informational or safety-related. Safety-relevant messages at this point would be meant to discourage the initiation of unsafe behaviors (e.g., unsafe to proceed, second train warning). Informational messages should not encourage unsafe behaviors (e.g., indicate a long delay before the train's arrival in the HRI).

Recommendation 8-6: Provide standardized message content on CMS at the HRI

CMSs located at the HRI should provide a limited set of messages that are based on established consensus standards.[8] In the absence of such standards, messages should be designed to initially notify drivers of an approaching train and subsequently cycle through a set of messages providing minimum required information to ensure safety (e.g., warning of train approach, time to HRI, time to clear the tracks). For new applications where standards do not yet exist, messages should be tested with roadway users to ensure comprehension [Also see: Recommendations 4-5, 4-24, 5-12, 6-7, 9-8, 9-9].

Rationale

Zaworski, Bell, Hunter-Zaworski, and Sacmaci (1996) have recommended using CMS messages for stopped motorists at the HRI to reduce driver uncertainty and increase the likelihood that drivers will comply with TCDs. Although no standardized set of messages has been developed, several suggested CMS message sequences have been proposed. Table 10 outlines two alternatives. Bell, Hunter-Zaworski, and Zaworski (1997), for example, suggest that CMSs should initially advise drivers to stay clear of the tracks when a train is approaching and then cycle through a set of messages, providing four basic information elements when a train has been detected. The National Plan for ITS Highway-Rail Intersection User Service #30 proposes more specific CMS wording. Both proposals include a provision for a default *All Clear* indication

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[8] One reviewer commented that in addition to standardized message content, the user should consider a standard format now recommended by the "traffic industry." This format is Line 1 (or frame 1): state the condition; Line 2 (or frame 2): state the location; and Line 3 (or frame 3): state the desired action.

when no train is present or approaching the HRI. Use of such an *All Clear* indication encompasses a different alerting strategy than current practice at active crossings (where the lack of a signal indicates no trains are approaching or present). The message sequence in the HRI User Service provides some additional information, including estimated time to clear the HRI and a release indication to notify drivers when it is safe to proceed. While the recommended messages below are helpful, the wording may not be optimal, and these examples do not take advantage of CMS graphics capabilities. In the absence of validated consensus standards, messages such as these should be evaluated for user comprehension.

Table 10. Proposed message content for CMS displays at the HRI

Bell et al. (1997)	National Plan for ITS Highway-Rail Intersection User Service #30 (1996)
(1) Default display indicating no train is present or arriving at the HRI. (2) A message warning drivers to stay clear from track when a train is approaching. (3) Indicate when the train will arrive. (4) “TRAIN CANNOT STOP BEFORE CROSSING!” (5) Indicate the direction to the nearest grade-separated crossing.	(1) “PROCEED” (HRI clear) (2) “TRAIN(S) ARRIVING, CLEAR THE INTERSECTION” (30–60 seconds before train arrival) (3) “STOP – DO NOT ENTER – WAIT FOR TRAIN(S) TO CLEAR CROSSING” (20–30 seconds before arrival) (4) “TRAIN(S) WILL CLEAR CROSSING IN ## SECONDS and/or WATCH FOR OTHER TRAIN” (5) “CAUTION” (after the train(s) clear the HRI) (6) “WAIT FOR PROCEED SIGNAL” (7) “PROCEED”

Recommendation 8-7: Provide cues as to the direction of approaching trains

This can be accomplished by spatially coding train location information using available in-vehicle speaker systems or trackside equipment to communicate train direction.

Rationale

Humans detect, localize, and automatically orient toward sounds and novel visual stimuli. Spatially coded signals (either in-vehicle or in the outside environment) allow drivers to locate the direction of the hazard (e.g., approaching trains). The location from which the signal emanates can be used to convey the direction of the train. Drivers may react to warning signals by first visually confirming the presence of the hazard. If the driver’s attention is guided more quickly to the approaching train by spatially coded signals, then appropriate evasive actions can occur more quickly.

Recommendation 8-8: Provide a release indication

Systems, particularly in-vehicle, must provide an indication to the driver when the conditions are safe to cross the tracks once the train has cleared the intersection (release indication). The system should allow for the need to re-issue a warning based on a second train event.

Rationale

This recommendation is targeted to passive crossings where no external release indications are present and drivers are required to assess whether it is safe to cross. Some concern does exist that drivers may assume it is safe to cross after the initial train has passed, but a second train may be approaching. An *All Clear* or *Proceed* message provides a redundant safeguard and a positive confirmation that the HRI is clear. Use of a release indication is a separate and distinct issue than that of issuing a default proceed or all clear message when no train is present or approaching the HRI. The release indication should be triggered in association with a warning message.

8.3.2 Signal Characteristics (How to Communicate)

Recommendation 8-9: Use CMS as a primary means to communicate HRI status

CMSs should be used to communicate HRI status information to motorists until in-vehicle systems become widespread [Also see: Recommendations 8-7, 8-8].

Rationale

Current fleet penetration for in-vehicle systems is too low for this to serve as a primary means of motorist communication, however helpful it may be to those who have such devices. HAR is inadequate because it requires an active response from the driver. Passive signs with active elements (e.g., flashers) have been used for some applications. CMS is preferred, however, because it permits the full set of helpful messages and can be viewed by all drivers.

Recommendation 8-10: Consider conspicuity enhancements for visual displays

If the train arrival warning system relies primarily on a visual display, then some conspicuity enhancements should be used to attract the driver’s attention to the display (e.g., flashing lights, strobes, dynamic features, or color on CMS). Supplemental audible alerts and warnings may also be used to enhance the conspicuity of visual displays. The use of an audible warning tone or message in association with a visual display in vehicles is strongly recommended, and supplemental audio cues may also be used at pedestrian crossings to enhance the conspicuity of the train arrival warning. Conspicuity enhancements that involve visual features are also recommended for MTWs [Also see: Recommendations 4-1, 5-3, 6-9, 8-22].

Rationale

Road users approaching the HRI are likely to be engaged in both transportation-related and non transportation-related tasks besides looking for trains. Those whose visual attention is not captured by the train itself (hazard) may be alerted to the danger by a visual display. However, the same demands on visual attention that may prevent the road user from noticing the train may interfere with them noticing the train warning display, especially if the display is not positioned directly in the road user's line of sight. Drivers must notice train arrival warnings if they are to be effective, and various conspicuity enhancements may help to draw attention to the display.

Recommendation 8-11: Avoid temporal countdown displays for motorists

Information on train arrival should be expressed in a manner that does not induce risky or undesirable behavior. Avoid use of countdown type warnings that provide a sequential time-based, countdown to train time to arrival. These types of formats may encourage risky driver behavior (drivers may race to attempt to beat the clock/train). Also avoid time estimates that imply greater precision than is available with the system or useful to roadway users [Also see: Recommendation 4-19].

Rationale

Although drivers may need to know estimated train arrival time to support their decisions, systems that continuously display a time-based countdown may encourage reckless behavior. Little or no research exists on behavioral impacts of these types of countdown displays, and this area should be studied further. Nevertheless, precise estimates may not be necessary and could erode driver confidence in the system if inaccurate. It may be more desirable to provide drivers with estimated time to clear the HRI rather than time to arrival. Furthermore, drivers may be able to base decisions on generalized time-to-arrival information without resorting to countdown type displays. Bell et al. (1997) proposed a possible configuration for a series of repeating CMS messages to alert motorists to the presence of an approaching train. The signs would rotate through a series of set messages: "High Speed Train Approaching," "Extreme Danger Train Speed 110 mph," "Train Will Arrive at Crossing in 1 min. 20 sec," "Train Cannot Stop Before Crossing." These messages repeat, and the time is updated. This configuration provides estimated train arrival time without necessarily providing a clock-like countdown.

Recommendation 8-12: Provide accurate and reliable information

Drivers must perceive train warning information to be accurate and reliable. Predictions of train arrival time should be as accurate as possible. Drivers will tolerate some inaccuracy (e.g., errors in time estimates, false alarms), without significant loss in trust. Strive for reliability rates that are more than 80 percent.[9] Systems should also be reliable under a variety of operational conditions, particularly low visibility situations. Systems must reliably detect trains when they are present [Also see: Recommendation 4-8].

Rationale

Unreliability leads to mistrust and uncertainty, possibly negatively impacting driver behavior and response to the system. Drivers may ignore system warnings or delay in responding to the warnings if the system is perceived to be unreliable. Research suggests drivers are likely to search for confirmatory evidence and delay braking as a consequence of false alarms; issuing a warning when no threat exists can erode driver confidence in the system and have measurable impacts in driver behavior (Chugh & Caird, 1999). Research suggests greater loss in trust at

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[9] The 80-percent reliability recommendation is based on empirical research on maintaining user trust. Higher levels may be required for other reasons, and, in particular, missed detections are much more safety critical than false positives.

50-percent reliability than 83-percent reliability. If drivers come to rely on the system exclusively and do not seek out confirmation, system failures could lead to catastrophic consequences. Systems should operate in degraded visual conditions, acting as a redundant pre-cue to approaching trains under low-visibility conditions (e.g., fog, rain, snow, or nighttime) where drivers may fail to detect approaching trains.

Recommendation 8-13: Minimize nuisance warnings to drivers not in potential conflict

Train arrival warning systems should be designed so that alerts and warnings are issued to approaching traffic and not to drivers who have crossed over the HRI (or traveling in the opposite direction, away from the HRI). The system should not activate unless the vehicle direction of travel will take it through the HRI [Also see: Recommendations 4-9, 4-18, 9-6].

Rationale

This is an annoyance issue (nuisance warnings). Systems should be designed to avoid or minimize nuisance alarms when the vehicle is in the vicinity of an HRI but not intending to cross the tracks. The warning zone around the HRI should be tuned according to the geometry and environment to prevent nuisance alarms.

8.3.3 Timing of Signals for Train Arrival Warnings

Recommendation 8-14: Issue warnings throughout the entire duration of the train event, but provide a way to reduce the nuisance potential of the warning

Once a driver has been alerted to the presence of a train (i.e., received the warning message), an in-vehicle system should provide a means to reduce the nuisance potential of the warning. Nevertheless, warning signals should continue to be issued throughout the entire duration of the train event to alert approaching traffic [Also see: Recommendation 4-18].

Rationale

Repeating alert and warning messages (or repeatedly cycling through the same warning) to drivers with in-vehicle systems can become a nuisance. This is particularly true for audible or voice warning messages. In-vehicle warning devices should provide a means to reduce the nuisance potential of an alert once it has been issued. This can be accomplished by muting or reducing the volume of any audible warnings after it has cycled through several times, limiting the number of times or cycles the warning is issued, including a driver confirmation button and changing the mode of the warning (change from audible to visual warnings) (Benekohal et al., 2000). The Minnesota Department of Transportation Field Operational Test of an in-vehicle signing system for school buses varied the number of repetitions based on the warning type: two repetitions of their audible warning for the HRI alert and eight repetitions of the tone upon initial detection for the train approaching warning. Tones should be repeated (re-activated) for each additional train warning signal (e.g., second train).

Recommendation 8-15: Inform roadway users at HRIs where extended advance warning times are used

The recommended warning time for activating a TCD is generally 20 seconds before train arrival. For ITS applications, such as blocked track warnings issued to train operators, vehicles must be cleared from the HRI more than 20 seconds before train arrival, so that if a vehicle or other object remains on the tracks after the gates descend, the train operator can be notified with enough time to initiate emergency braking procedures. If warning times (gate closings) at certain HRIs equipped with ITS technology are significantly longer than the warning times provided at conventional active crossings, roadway users should be informed about the estimated time until the train arrives or at least given an indication that the particular HRI has a longer than normal advance warning time [Also see: Recommendation 4-7].

Rationale

Warning times at active crossings should be consistent with roadway users' expectations. If flashing lights and gates are activated more than 20 seconds before train arrival, roadway users may become impatient waiting for the train to arrive at the HRI and assume that the gates are malfunctioning. This may lead to risky behaviors, such as driving around the gates.

8.3.4 Coordination with External Controls

Recommendation 8-16: Coordinate ITS warnings and non-ITS traffic control devices

In general, similar messages should occur at similar times for all information sources. Some ITS applications, however, may allow for situation-specific timing that is more precise and appropriate than non-ITS applications. For example, warning time algorithms could incorporate vehicle speed, vehicle type, road surface condition, traffic, or train speed. These advantages should not necessarily be sacrificed to maintain identical timing of all information sources. However, the effects of variable timing, particularly if only some vehicles receive the information, should be considered in system design. The possible disadvantages of variable timing of messages across roadway users should be considered along with the advantages of providing more advance warning to drivers who have in-vehicle systems [Also see: Recommendation 4-29].

Rationale

Warnings should be consistent with driver expectations and highway signing and controls, and they should not encourage drastic behavioral differences in equipped versus nonequipped vehicles when approaching an HRI. Vehicles equipped with in-vehicle warning systems may stop (or slow) in response to a warning message (e.g., train approaching); however, these types of actions may not be expected or understood by surrounding traffic whose drivers may not have benefit of this information. In-vehicle warnings should be designed to supplement existing HRI warning systems available in the external environment (both passive and active treatments). The information provided by the in-vehicle display should agree with TCDs that drivers encounter; otherwise drivers may lose confidence in the system.

8.4 Specific Recommendations for MTWs

Table 11 groups recommendations for MTWs[10] under three topics. Each topic includes individual recommendation statements.

Table 11. Recommendations for message content and message comprehension for MTWs

Message content and message comprehension for MTWs

17. Use an active caution message.
18. Convey all important elements of the warning message either explicitly or implicitly.
19. Ensure complete message comprehension.
20. Present consistent behavioral cues during multiple train events.

Signal conspicuity for MTWs

21. Attract the attention of at-risk road users.
22. Enhance conspicuity with visual features.
23. Ensure that both text and graphic display elements are legible.
24. Supplement MTW displays with acoustic signals.

Message timing and phasing for MTWs

25. Initiate MTW before first train passes.
26. Limit the length of message phase times.

MTWs for drivers

27. Use the following components of MTW displays for motor vehicle traffic.
28. Install a roadway-based MTW display in a location appropriate for motor vehicle traffic.

MTWs for pedestrians

29. Provide an MTW to pedestrians at HRIs where more than one train often passes through the HRI in close proximity.
30. Use the following components of MTW displays for pedestrians.
31. Install an MTW display in a location appropriate for pedestrian traffic.

8.4.1 Message Content and Message Comprehension for MTWs

Recommendation 8-17: Use an active caution message

The MTW display should contain distinct elements to convey the message that there is a hazard present that requires caution. This should include an active display component.

Rationale

The general message that a hazard is present and caution is required may be conveyed by a signal word (e.g., "WARNING" or "CAUTION"), sign shape and color (e.g., yellow, diamond in the MUTCD), icon (e.g., ISO "!"), or supplementary signal (e.g., amber flasher). Some portion of this message should be active (i.e., present only when the second train threat is present); passive elements, such as sign background shape or color, are not sufficient because they do not indicate to the road user a change in status from the time they were initially encountered. Components of the message that describe the event (second train) should not in themselves be assumed to evoke an immediate and consistent sense of danger. A need to convey an immediate

[10] Although MTW systems are currently in use, one reviewer expressed reservation, arguing that it is not possible to detect multiple trains and provide accurate warnings "except in the simplest of situations and then not to a degree that is reliable enough to make a railroad's law department recommend use." Another reviewer expressed a related concern, arguing that because MTW collisions are "99.999 percent likely to be litigated," the cost-benefit of developing an adequately accurate system may not be favorable.

and unambiguous sense of threat exists to prevent an impulsive roadway user from proceeding before processing the complete message.

Recommendation 8-18: Convey all important elements of the warning message either explicitly or implicitly

The MTW should include an unambiguous indication that a subsequent train is about to reach the HRI after the first train. This message should be appropriate for all viewers, including the non-English literate. The viewer should understand (1) the nature of the event, (2) the consequence of the hazard, and (3) how it should be avoided. It is not necessary that each of these elements be explicitly and separately stated or illustrated, but each must be conveyed. In particular, the consequence may be assumed to be conveyed if the hazard event of the approaching train is understood.

Rationale

The nature of the threat and how to avoid it are elements of effective warning devices. No formal indication is in the literature that existing MTW implementations meets this requirement.

Recommendation 8-19: Ensure complete message comprehension

The display should reliably convey both the general message that a danger is present and the specific message that another train is approaching. Comprehension by the intended user population should be confirmed by appropriate testing [Also see: Recommendations 4-6, 4-21, 7-5].

Rationale

Good warning practice requires that a communication device clearly convey (1) that this is a warning message and (2) the type of hazard, its consequence, and how to avoid it. The warning aspect helps to direct attention to the message and induce caution, while the specific hazard information is necessary for good compliance. Although a particular display successfully conveys one of these aspects, the viewer may not understand the other aspect. Displays used for MTWs generally do not appear to have been formally evaluated for road user comprehension, with the exception of the Los Angeles MTW application. They reported that a survey of pedestrians at the Vernon Avenue site found a very high proportion understood that caution was necessary, but very few (4 percent) understood the specific second train situation. This indicates the need for warnings based on testing with appropriate user populations.

Recommendation 8-20: Present consistent behavioral cues during multiple train events

Systems intended to detect and communicate multiple train events should provide drivers with a consistent set of behavioral cues and expectations. This includes keeping active warning system components, if present (e.g., gates, bells, lights) engaged in-between train events. Ensure that roadway users do not get conflicting signals from gates, warning lights, and MTW displays. In particular, gates should not start to move into their upright position during multiple train events [Also see: Recommendations 4-7, 4-28].

Rationale

The sight of a first train clearing the crossing is a cue to roadway users that it is safe to cross the HRI. MTWs, when activated, must act to overcome this cue by presenting a clear message that it is not yet safe to cross. Active controls (gates, lights, bells) also represent an important primary cue to drivers signaling when the HRI is safe to cross. Therefore, it is important that the information that they provide is coordinated and completely consistent with information provided by the MTW, including any supplemental MTW displays. Gates in particular serve as a strong visual cue and are likely to attract the driver's attention if they begin to retract to their upright positions (this event will likely cue drivers to prepare and/or start to move). An ascending gate that stops after only a few seconds and then immediately descends again as it is activated by a second train may be perceived to be malfunctioning and ignored. This problem would be especially serious at locations where false gate activations are known to occur. Moving gates may also attract attention away from critical visual displays used to inform drivers about multiple train events. Conflicting signals, such as gate movement when it is not safe for drivers to cross the HRI, erode confidence in the system and may lead to dangerous behaviors, such as driving under or around gates. For these reasons, gate movement should be retarded during multiple train events. The Transit Cooperative Research Program (1999) describes some specific strategies to prevent the gate behavior described above (known as gate pumping).

8.4.2 Signal Conspicuity for MTWs

Recommendation 8-21: Attract the attention of at-risk road users

Visual displays for MTWs, once activated, should quickly and reliably attract the attention of at-risk road users as defined by their location or actions. Dynamic visual or acoustic display features (e.g., strobes) may be considered [Also see: Recommendations 4-1, 4-13, 7-6, 8-22, 8-24, 11-3, 11-4].

Rationale

Roadway users are unlikely to monitor an inactive MTW display. Their attention will probably be directed toward the passing train, gates, up-road, up-track, or elsewhere. Furthermore, the road user may not expect to encounter a sign at the HRI, particularly not at the MTW signal's location. When a sign location is inconsistent with driver expectancy, sign detection is slower and less reliable. If the visual display does not draw attention at the time a hazard is detected, the roadway user may proceed without an opportunity to receive the warning. Conspicuity will be a function of the location of the display(s), the number of displays, and the features of displays. Conspicuity when activated is a necessary consideration for both infrastructure-based and on-board systems. The at-risk users may include motor vehicle operators, pedestrians, and bicyclists, depending on the application. Those at-risk are defined by their location relative to the tracks and trains and the time for track clearance.

Recommendation 8-22: Enhance conspicuity with visual features

Where the display cannot be located near the target road user's probable line of sight, the conspicuity of the display should be enhanced. Static attributes of visual displays, such as size, brightness, color, and contrast, all influence whether the display will be noticed. However, dynamic changes will be more effective because (1) they are strong contributors to conspicuity and (2) they draw attention at the time the display is relevant, not at irrelevant times. Therefore, flashing beacons or strobes are recommended for roadway-based displays, even if other static enhancements are made. Dynamic elements should not interfere with display legibility [Also see: Recommendations 4-1, 5-3, 6-9, 7-4, 8-10].

Rationale

Road users must be aware of the MTW sign only when it is activated. Static improvements to conspicuity are not sufficient because once viewers detect the inactive display, they may not direct further attention to it. The message display alone on an activated roadway sign may not be sufficient to ensure it is noticed. Even if animation is used, the likely positioning of the sign means that roadway users may not notice it unless an effective stimulus for peripheral vision exists. Adjacent flashing amber beacons, or bright strobes, are typical treatments for enhancing roadway sign and signal conspicuity. These enhancements must not create glare, especially if used at night.

Recommendation 8-23: Ensure that both text and graphic display elements are legible

Text and graphic elements must be legible from all likely viewer positions. Specific wording and/or icons should be tested to verify roadway users understand them. A mix of text and graphics may be used, but this should not result in clutter, small images, or long sequences of displays. Text should not scroll. Iconic elements should ideally include recognizable images of the tracks, trains, and road user (vehicle or pedestrian). It may be desirable to have the display reflect the actual spatial and temporal sequence of events (e.g., direction of train movement), but any degree of benefit is unknown [Also see: Recommendation 4-3].

Rationale

The MTW must meet good display criteria as would any sign. No specific wording and pictorial content are recommended because alternatives should be tested for comprehension. Since the nature of the hazard event is defined by the relationship of the trains, tracks, and road user, however, it would seem that the image should include all three elements. No specific recommendation is made with respect to the perspective view that should be shown (e.g., overhead, profile, or linear perspective). It may be desirable to have the display reflect the actual sequence of events; for example, if the first train is on the near track approaching from the left and the second train is on the far track approaching from the right, the display accurately reflects this relationship. It is conceivable that, if some location or direction of approach is shown that does not match the actual situation, there could be some confusion for the road user, and visual search might be misdirected. This could be of most concern where more than two tracks exist and the potential exists for a subsequent train arriving on any track and from either direction. However, because it is not known whether showing a specific relationship is likely to have ultimate safety consequence, it does not seem warranted at this point to require a display to be sensitive to the actual location and direction of the first and subsequent trains.

Recommendation 8-24: Supplement MTW displays with acoustic signals

An acoustic signal may supplement the visual display. The signal should originate from the direction of the visual display. The appropriateness of a supplementary acoustic signal must be considered in the context of other acoustic signals (e.g., bells) and noise (e.g., passing train) present in the environment. For the intended road user, it must be detectable, localizable, and easily discriminated from other sources.

Rationale

Acoustic signals may enhance conspicuity and perceived urgency, and they may serve as useful supplements to visual MTW displays. For onboard warning systems, the requirements for acoustic warnings probably are not unique from other types of warnings. For infrastructure-based applications, applications issues differ somewhat for pedestrian and motor vehicle applications. Under ideal conditions, an acoustic cue associated with the visual display could enhance the ability of the display to draw attention. This can only be achieved if the signal itself orients attention, and that attention is directed toward the location of the visual display. This may be difficult to achieve for road users inside vehicles but may be more practical for pedestrian applications. In either case, because the MTW occurs during the pass-by of the initial train, any acoustic signal will need to occur in the context of train noise, bells, or other audible warning devices associated with the normal operation of the gates and flashing light signals. An acoustic MTW signal should only be used if it can practically meet the needs of detection, discrimination, and localization while being environmentally appropriate.

8.4.3 Message Timing and Phasing for MTWs

Recommendation 8-25: Initiate MTW before first train passes

The MTW display for stopped traffic or pedestrians should activate as soon as the multiple train event is detected. The message must initiate sufficiently before the initial train passes so that the entire warning message can be displayed and understood. The range of the warning activation envelope should be extended for a subsequent train once the initial train has activated the gate.

Rationale

Impatience and impulsiveness are likely factors in crashes with a second train. A message, therefore, must have its impact quickly. If the onset of the warning is late or if the display takes a long time to cycle, the impatient road user may react before processing the entire message. The road user may initiate action in response to the passing of the end of the train or the initiation of the gate rising. Once the road user begins to move forward, it may become very difficult to read a roadside warning display because the viewing angles become extreme. In-vehicle displays may also be less likely to be noticed because attention will be directed outside at the tracks and roadway ahead. The MTW display should to immediately inhibit inappropriate road user actions. The entire MTW message (possibly consisting of multiple phases) should be displayed before the end of the first train passes because impatient roadway users may try to cross the tracks at this time. A scenario of particular concern is where the initial train passes, the crossing signal display is terminated, and gates begin to rise before the entry of the second train into the warning activation zone. Vehicles could become trapped, or road users may think that the signals and gates are malfunctioning. To prevent such problems, the advance warning time for the second train could be lengthened to preclude premature termination of the initial warning. By this logic the warning time for the second train should be extended by at least the amount of time remaining until the gate reaches its upright position.

Recommendation 8-26: Limit the length of message phase times

If a dynamic display consists of a sequence of phases, the initial phase should inhibit the initiation of movement by the road user. This phase should be of sufficient duration so that the viewer has the opportunity to orient toward the display and interpret the text or image. Subsequent phases should allow enough time for the viewer to process the information, but the total duty cycle for the display should not be so long that road users are discouraged from attending to the full cycle. Phase times will generally be in the 1.5–3.5 second range, depending on complexity [Also see: Recommendation 4-14].

Rationale

Some MTWs have employed a sequence of phases. This may have the advantage of simplifying the image and message for any given phase and the disadvantage of requiring the viewer to attend to multiple displays to get the full message. The MTW must quickly inhibit driver action. For this reason, the initial phase should include an easily perceived message or image (e.g., "stop," "warning," "danger," lights, or sounds). The duration of the phase should include time to orient toward the sign and time to process the image. Processing times may be taken as a minimum of about 1 second; allowing for orientation, this suggests a minimum phase of 1.5 seconds for simple messages or images. Complex images may require substantially longer times (some formulas for roadway signs suggest estimating 1 second per symbol and 0.5 second per word or number). An upper bound on the order of 3.5 seconds is suggested based on the assumption that if a phase takes longer than this, the image may be too complex to warrant being part of a phased sequence. The total duty cycle for the display is the sum of the durations of all the phases. An impatient road user needs to get the message in a reasonable time, but little empirical basis exists for defining an acceptable maximum for this application.

8.4.6 MTWs for Drivers

Recommendation 8-27: Use the following components of MTW displays for motor vehicle traffic

MTW displays intended for motor vehicle traffic, whether roadway based or on-board, should be composed of the following elements:

- An indication that a hazard exists and this is a warning message.
- An iconic indication that a subsequent train is about to arrive at the HRI after the current train.
- A text (or in-vehicle voice) indication of a subsequent train, unless the iconic display is demonstrated to have high comprehension for the range of anticipated viewers.
- For roadway-based displays, a flashing amber beacon mounted adjacent to the display panel that is activated throughout the display cycle.
- An acoustic cue at the onset of an on-board display. An acoustic signal is optional for a roadway display. Acoustic signals for roadway-based MTWs should continue throughout the warning display cycle and should be localized from the position of the visual display. Drivers must be able to easily discriminate MTW acoustic cues from other acoustic signals used at the HRI (bell, horns).

Rationale

The recommendation given here is based on several recommendations listed above. No basis exists for recommending specific icons or wording for the display, so candidate messages should be evaluated by testing with drivers.

Recommendation 8-28: Install a roadway-based MTW display in a location appropriate for motor vehicle traffic

For MTWs that are infrastructure-based (on the roadway), the visual display(s) should be located at a position appropriate for motorists, in all travel lanes, stopped at the track. If possible, the display should be located within a 20-degree cone of vision around the driver's forward line of sight, or as close to this as possible, for motorists stopped at the track. Mounting height should be at a minimum 15 feet and at a maximum 25.6 feet. The display should be oriented so that the images and text are legible, despite oblique viewing angles, for motorists in all lanes. The MTW should not be located where it will be obscured by passing trains. Viewer eye position may be assumed to be 6 feet from the lowered gate position, with an eye height of 3.5 feet.

Rationale

The motorists of most concern for this display are those at the front of a queue at the HRI. While other vehicles behind the lead vehicle may pass waiting traffic to circumvent signals or gates, the problem of viewing angle is not as severe. For a vehicle stopped near the track, the angle of the display, relative to the driver forward line-of-sight, may be large in the vertical dimension for cantilever displays mounted above the roadway or in the horizontal dimension for displays mounted at the roadside. The greater this visual displacement, the less likely drivers will notice the signal. Furthermore, whether vertically or horizontally displaced from the driver, the face of the display may need to be angled toward the viewer to prevent illegible displays at the most oblique viewing angles. The criterion in the guideline for the 20-degree viewing angle comes from MUTCD guidance (Section 4D.15) on the placement of traffic signals (Federal Highway Administration, 2003). Because the MTW display must function as a stop indication, criteria for traffic signals are a useful guide; Section 4D.15 contains further detail on signal placement for roadway intersection signal control applications. The cone of vision around the driver line of sight typically is considered good within 10 degrees and adequate within 20 degrees (McKinley, 2001). Mounting height requirements also come from Section 4D.15. The mount must be low enough so that the vehicle roof line does not obscure the display from the driver position. The assumed viewer position of 6 feet from the lowered gate is a worst-case estimate. Vehicles with relatively short bumper-to-driver seat positions place the viewer's eyes about 6 feet from the bumper. Assuming a lead vehicle pulls up immediately in front of the gate, the viewer would be about 6 feet from the gate. The driver eye height assumption of 3.5 feet comes from the use of this value for highway sight distance design purposes. Using these values and assuming an 18-foot cantilevered mounting height for the display, the MTW sign would need to be at least 40 feet downstream from the gate position to remain within 20 degrees. Lateral viewing angles depend on the roadway geometry. Although 20 degrees is specified as a target viewing angle, even this may be problematic, given the possible driver focus of attention on the gate immediately in front of the vehicle and the fact that no expectancy may exist for a sign in this location.

8.4.5 MTWs for Pedestrians

Recommendation 8-29: Provide an MTW to pedestrians at HRIs where more than one train often pass through the HRI in close proximity

Rationale

Pedestrians are often more susceptible than motorists to collisions with trains during multiple train events. This is because pedestrian behavior is more difficult to control, especially without the presence of restrictive devices, such as gate arms or pedestrian swing gates. MTWs can aid pedestrians' decisionmaking by confronting the incorrect assumption that it is safe to cross after the first train has passed and alert them to a specific hazard. Second Train Approaching signs have been recommended for use at locations where two or more LRT tracks are present and LRV typically have short headways due to many trains running or due to scheduled meet points in the operating plan (Transit Cooperative Research Program, 1999).

Recommendation 8-30: Use the following components of MTW displays for pedestrians

MTW displays intended for pedestrians should include the following elements:

- An indication that is a hazard exists and this is a warning message.
- An iconic indication that a subsequent train is about to arrive at the HRI after the current train.
- A text or voice indication of a subsequent train, unless the iconic display is demonstrated to have high comprehension for the range of anticipated viewers.
- An acoustic signal is optional. Acoustic signals should continue throughout the warning display cycle and should be localized from the position of the visual display and easily discriminated from other acoustic signals used at the HRI (bell, horns).
- A flashing amber beacon may be required if display location criteria of Recommendation 8-21 are not met.

Rationale

The recommendation given here is based on several recommendations listed above. No basis exists for recommending specific icons or wording for the display, so any candidate messages should be evaluated by testing with pedestrians of various ages including those who have sensory, cognitive, or motor disabilities.

Recommendation 8-31: Install an MTW display in a location appropriate for pedestrian traffic

An MTW visual display(s) intended for pedestrians should be located at a position appropriate for pedestrians stopped 6 feet from the nearest track. The display location should be within a 20-degree cone of the forward line-of-sight or as near to it as possible. The display should be oriented so that the display is legible, despite oblique viewing angles, for pedestrians at any lateral point across the pedestrian right-of-way. If the display is displayed beyond 20 degrees for some viewing positions, consider enhancements such as greater size, dynamic elements, or acoustic signals.

Rationale

The need for the display to draw viewer attention is the same for pedestrians as that for motorists. A display intended for pedestrians may be the same display intended for motorists or may be an independent display. In either case, the location must be appropriate for pedestrians. The constraints on placement relative to viewer position may not be as severe for pedestrian-oriented displays as they are for roadway-based motor vehicle displays. Pedestrian displays can generally be mounted lower, lateral displacement does not need to be great, and vehicle components (roof, pillars) are not present to obscure peripheral detection. Nonetheless, pedestrians may still be standing near the tracks so that oblique viewing angles can be large. Therefore, a reasonable minimum distance to assume might be the edge of the train dynamic envelope, which is generally 6 feet from the track according to the MUTCD, Section 8B (Federal Highway Administration, 2003).

9. Advance Information about the HRI and Dynamic Route Guidance

9.1 Background

While the previous chapter focused specifically on ITS applications for warning roadway users about train arrival at the HRI, this chapter focuses on applications that may improve safety and travel efficiency by giving roadway users other types of information in advance of the HRI. The two application areas covered are (1) providing advance information about safety-relevant features of the HRI and (2) presenting route guidance information about HRIs before route decision points. The emphasis is on providing information to motorists because this group is the most likely to receive benefits from the implementation of HRI advance warnings and route guidance information. This chapter considers what information to present and how to present it, as well as the likely behavioral impacts of such information. Advance information about the HRI can affect driving behavior in positive ways. For example, motorists may react to the information appropriately by reducing speed, increasing searching for trains, or making sound navigational decisions about alternate routes and timely maneuvers necessary to carry out these choices. However, there may be other, unintended consequences of providing this information, such as driver annoyance, information overload, or increases in unsafe driving behaviors [Also see: Recommendations 4-16 through 4-19].

ITS technology introduces the possibility that fixed roadside warning signs may be supplemented or replaced by intelligent systems. Such systems may be capable of presenting a richer and more distinct set of cues to promote proper behavior and facilitate decisionmaking. In current practice, the standard Crossbuck (R15-1) and Advance Warning (W10-1) signs are sometimes supplemented by other roadside signs that warn of unusual or hazardous conditions related to the HRI, including unusual grade crossing geometry and types of rail traffic. Roadway users may benefit from knowing in advance about potentially hazardous geometric features of the HRI, including limited sight distance, high-profile (humped) crossings, multiple tracks, skewed crossing angles, and roadway intersections and signals near the HRI, as well as the type of traffic controls present (active or passive). Other information about rail traffic, such as the presence of high-speed trains, mixed-rail operations, and the potential for multiple train events, may also be useful to motorists and could be communicated through ITS displays. Additionally, ITS-based HRI warnings may prove to be a viable, relatively inexpensive alternative to installing active controls (gate arms, bells, and lights) at passive crossings.[11]

Although conventional supplemental grade crossing signs are limited to warnings regarding fixed characteristics of the HRI, ITS applications are capable of presenting dynamic warnings regarding transient states, such as road surface conditions, obstacles on or near the track, and queued traffic. To avoid fixed or transient conditions, such as lengthy delays, drivers who have been alerted to these conditions may choose to take an alternative route, especially if alternative route guidance is provided.

Route guidance information may be presented as an integrated part of in-vehicle displays or on roadside CMS systems. ITS systems may be able to draw on information from many sources to predict the time until an HRI will be clear and expected travel times on alternate routes.

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[11] One reviewer cautioned that it is an "urban myth" that "ITS crossings will be less expensive than conventional systems."

Information such as anticipated train arrivals, projected delays, travel times, and route restrictions (for carriers or vehicles with low-ground clearance) should be incorporated into route guidance systems.

Dynamic advance warnings and the sophisticated route guidance capabilities mentioned here will require sensor and information processing technology to change messages to motorists as conditions near the HRI change and as conditions on alternative routes change. Existing technologies, such as video detection, loop sensors, and Global Positioning System (GPS), among others, can play a role.

9.2 Key Human Factors Issues and Need for Guidance

9.2.1 Issue: Information Timing

To achieve maximal effectiveness of HRI warnings or actionable route guidance, information must be presented to motorists in a timely manner. Adequate (minimum) timing is a function of fairly well understood variables, such as the time required for motorists to perceive and process the information, and time required to perform any necessary actions (e.g., decelerate, choose alternate route, look for trains), and some simple constraints exist. For example, information that may inform the driver's choice of route must be presented (and acted upon) in advance of route decision points. On the other hand, it is not clear how much advance time is optimal for different kinds of information.[12] Research is needed to specify a maximum amount of advance time for alerts, warnings, or route guidance information. Presenting information too far in advance of when it is needed may cause annoyance and will create an unnecessary burden on the driver's memory.

9.2.2 Issue: Information Amount

The amount of information to present to motorist is a major human factors consideration. Although this issue applies to virtually any application of driver information, some issues are specific to HRI information. For example, to reroute a vehicle to another HRI location, the motorist could be given additional instructions, such as directions for an alternate route. Although the potential benefits are obvious, such information may increase driver information load and divert attention from the driving task. Similar concerns arise with any attempt to present multiple messages.

9.2.3 Issue: User-Specific Information

User-specific information should be directed to all targeted motorists. Additionally, targeted information should not be presented to any motorists for whom the message is irrelevant. This may be relatively simple for in-vehicle systems but more difficult for presentations external to the vehicle. The ITS system must recognize the vehicle or its characteristics. For example, ITS messages related to HAZMAT restrictions or humped crossings are nuisances for most drivers, and ideally the system should discriminate those vehicles for which the message is relevant. If a message is presented externally and targeted to one vehicle, it is likely that many other motorists

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[12] One reviewer reported that in his/her experience, the characteristics of the traffic are a factor in when to present information. Commuters require "far less time to respond and are more likely to do so" than travelers from "outside the area like tourists."

will notice it and perhaps be distracted by it. Another concern is that for in-vehicle messages and external messages, a targeted motorist may notice a relevant message but decide that the message is irrelevant. The message duration, activation and deactivation method, and wording may all affect the likelihood that the relevance of user-specific information will be misinterpreted.

9.2.4 Issue: Message Medium and Format

Current non-ITS HRI warnings commonly use textual and/or iconic messages. When implementing or upgrading advance HRI warning devices using ITS technology, it is important to present warnings in a way that is consistent with the mental models of message recipients. The use of CMS is fairly consistent with current warning signage in both location and appearance. The MUTCD (Federal Highway Administration, 2003) supports the use of CMS for warning applications, and the roadside location of such warnings is similar to typical non-ITS signage.

Another way to present HRI warnings to drivers is to transmit information wirelessly to the in-vehicle environment. An advantage of this message format relative to standard sign plaques and CMS is that a greater amount of information can be given to the motorist, and this information can be tailored to individual needs. Unlike CMS, however, in-vehicle presentation of HRI information is novel and inconsistent with current signage. Furthermore, the presence of in-vehicle visual displays may require drivers to take their eyes off the road, potentially leading to driver distraction. An additional difficulty of in-vehicle displays is that the display must be installed in a variety of vehicles, each of which has a unique configuration that may prevent uniform installation. Because of the novelty of this approach, the risk of distraction, and the cost of vehicle fleet instrumentation, this application may be most likely to succeed if targeted only to vehicles deemed to be at high risk for certain hazards (e.g., heavy trucks, buses, vehicles with low ground clearance, and vehicles containing hazardous materials).

9.3 Recommendations

Table 12 groups recommendations for providing advance information about HRI and route guidance under three topics. Each topic provides the individual recommendation statements.

9.3.1 Advance Information about the HRI

Recommendation 9-1: Provide advance information about HRI status and characteristics subsequent to a general warning about the presence of the HRI, except where this conflicts with other criteria for message placement or timing

For roadway-based displays, this means the message about HRI status should be located between the Advance Crossing (W10-1) sign and the crossing. The display, however, must meet the location criteria in described in Section 5.3. For in-vehicle displays, the message about HRI status should follow the general warning about the presence of the crossing or may be integrated with that message.

Table 12. Recommendations for advanced information about the HRI

Advance information about the HRI
1. Provide advance information about HRI status and characteristics subsequent to a general warning about the presence of the HRI, except where this conflicts with other criteria for message placement or timing.
2. For in-vehicle systems, include advance information about fixed features and hazards at the HRI that is typically conveyed by conventional roadside signs.
3. Provide motorists with additional advance information about transient conditions at the HRI that is not typically conveyed by conventional roadside signs.
4. For advance information to motorists about potential hazards at the HRI, identify the hazard and advise the driver how to respond.
5. Provide advance information about the HRI only to roadway users for whom the information is relevant.
6. Distinguish between active and passive crossings when providing advance information about HRI location.
Route guidance
7. Develop consensus standards for providing dynamic route guidance through or around HRIs.
8. Standardize CMS messages for dynamic route guidance so that they have a consistent format with other CMS messages to motorists.
9. Route guidance concerning the HRI should be based the most current and complete information available.
10. Provide motorists with dynamic route guidance information that incorporates predicated as well as current conditions at the HRI.
11. Support the driver's navigational decisions by providing all relevant information about the HRI in advance of route diversion points.
12. Provide a driver-oriented reason when an alternative route is recommended to divert around the HRI.
13. If an alternate route is recommended over the primary route across the HRI (driver's typical route or normal best choice route), provide an estimate of travel time on the alternative route.
14. Emphasize quantitative information over qualitative information when expressing delays associated with the HRI.
15. Recommend alternative routes when opportunities for significantly reduced travel times exist as defined by the driver's personal preferences or when emergency situations arise at the HRI.
User control
16. Give the user control over the types of advance information about the HRI that will be presented in the vehicle and the conditions that will trigger recommendations for selecting alternative routes.

Rationale

The recommendation for roadway-based sign placement is consistent with recommendations for fixed signs in National Cooperative Highway Research Program (NCHRP) Report 470 (Lerner et al., 2002). If the message about HRI status follows the message about the presence of the crossing, the meaning may be clearer and have more impact. The supplementary message is less likely to interfere with perception and processing of the standard highway sign. For some hazards, however, this placement might not meet the criteria of Recommendations 5-1 and 5-2 and the message may have to be presented earlier. For example, if the problem is that a traffic queue has backed up from the crossing, the driver must be informed sufficiently in advance of the queue, not the crossing. If a steep grade and possible slippery conditions lead to the crossing, the driver must be informed sufficiently in advance of the hill. If the warning is specific to heavy trucks, placement criteria must be based on stopping distance criteria for such vehicles. For in-vehicle messages, it may be possible to incorporate the specific message about HRI status with the general warning about HRI presence (e.g., obstacle is blocking rail crossing ahead). In no case should a general warning follow a specific warning about HRI status.

Recommendation 9-2: For in-vehicle systems, include advance information about fixed features and hazards at the HRI that is typically conveyed by conventional roadside signs

The roadside signs listed below, which are included in the MUTCD (Federal Highway Administration, 2003), provide advance information about the HRI to all motorists. An ITS-based in-vehicle navigation or warning system could be used to notify motorists about these same conditions when the message is relevant, but not when the message is irrelevant.

Signs located at, or in advance of, the HRI that may be supplemented by in-vehicle displays

- EXEMPT crossing (W10-1a, R15-3)
- TRAINS MAY EXCEED 80 MPH (W10-8)
- NO TRAIN HORN (W10-9)
- NO SIGNAL (W10-10)
- NO GATES OR LIGHTS (W10-13)
- USE NEXT CROSSING (W10-14a)
- ROUGH CROSSING (W10-15)
- TRACKS OUT OF SERVICE (R8-9)
- Railroad tracks close to (within 100 ft) parallel roadway (W10-2, W10-3, W10-4)
- Low ground clearance (W10-5)
- Limited storage space near crossing (W10-11, W10-11a, W10-11b)
- Skewed crossing (W10-12)
- Number of tracks (R15-2)
- Emergency notification sign (I-13, I-13a) (could be displayed on demand)

[Also see: Recommendation 4-24]

Rationale

Although standard advance warning signs are usually only readable by an approaching motorist for a short period of time, in-vehicle notification could be triggered when the motorist is further upstream of the HRI and could remain readable (or audible) for a longer period of time after the motorist passes the fixed advance warning sign. Alternatively, in-vehicle systems may provide the capability to replay an alert message that was missed. In-vehicle systems may also provide information that is tailored more closely to the motorist's needs, perhaps playing only a subset of the possible alerts and warning messages that are relevant to the motorist at the time or based on personal criteria established by the motorist [Also see: Recommendation 9-16]. The level of redundancy between in-vehicle warnings and roadside signage may be increased when the visibility of roadside signs is reduced by adverse weather or lighting conditions.

Recommendation 9-3: Provide motorists with additional advance information about transient conditions at the HRI that is not typically conveyed by conventional roadside signs

In addition to the HRI information typically provided to motorists on roadside signs (see Recommendation 9-2), ITS-based systems should provide advance warnings to motorists (either via in-vehicle displays or roadside displays) about transient characteristics of the HRI that may present a special hazard. Such characteristics include the following:

- Limited visibility at the HRI due to atmospheric conditions, such as fog, smoke, heavy rain, or snow
- Hazardous road surface conditions near the HRI (ice on roadway)
- Obstacles on or near the track (stalled vehicle, railway maintenance equipment, train stopped in HRI)
- Queued traffic upstream of the HRI (this may be especially important where the approach to the HRI follows a curve or where sight distance to the HRI is otherwise limited)
- Limited storage space beyond track due to a downstream traffic queue (with a warning to not stop on tracks)
- Malfunctioning gates and lights

Because no standard messages or icons exist for these hazards, displays should be evaluated for comprehension and should use a standard warning format [Also see: Recommendations 4-3 through 4-7].

ITS technologies make it possible to detect transient hazardous conditions and to convey this information to roadway users. Advance warning of these conditions allows drivers more time to prepare and respond to the hazard.

Recommendation 9-4: For advance information to motorists about potential hazards at the HRI, identify the hazard and advise the driver how to respond

For example, in advance of a passive crossing, most drivers should be warned about the presence of the HRI and told to slow down and search for trains. Other drivers, such as school bus drivers, may be reminded to stop at the HRI and search for trains [Also see: Recommendation 8-4].

Rationale

Depending on the nature of the hazard and urgency of the warning, drivers may not know how to react. By briefly stating a recommended course of action, drivers do not have to spend time evaluating their possible responses. For extremely urgent warnings such as collision avoidance, the recommended course of action (i.e., STOP) may be more important than the reason for the warning.

Recommendation 9-5: Provide advance information about the HRI only to roadway users for whom the information is relevant

Use warning system intelligence to limit advance information to those drivers for whom the information is important or to preclude the display for those drivers for whom it is clearly not relevant. The ability to do this depends on what attributes the ITS application can recognize. For example, the system might recognize vehicle attributes (e.g., clearance), special requirements (HAZMAT, school buses), planned route (through the vehicle's navigation system or via tracking), or even driver attributes (e.g., familiarity with the specific HRI). If presentation of a message cannot be restricted to certain vehicles, it may sometimes be appropriate to identify the intended user by a message heading (e.g., TRUCKS) so that other road users do not have to fully process the message.

Rationale

Limiting the message to drivers who require it will help reduce message proliferation and improve credibility. This should benefit user acceptance, reduce annoyance, and promote attention to and compliance with the warnings [Also see: Recommendations 4-9, 4-18, 8-13].

Recommendation 9-6: Distinguish between active and passive crossings when providing advance information about HRI location

Rationale

Providing information about the type of crossing is helpful for setting roadway users' expectations about the HRI (e.g., active crossings are more conspicuous, have more train traffic). Approaching motorists who know what type of HRI to expect may see the HRI sooner and react more appropriately than those who make an incorrect assumption about the type of HRI that they are approaching.

9.3.2 Route Guidance

Recommendation 9-7: Develop consensus standards for providing dynamic route guidance through or around HRIs

These standards should evolve as technology changes to maintain a balance between the needs of the individual roadway user with the needs for overall traffic network efficiency and safety. ITS systems should be designed so that motorists appreciate the capabilities and limitations of the system and the need for overall traffic management, while retaining a sense of control over their own vehicles and route choices [Also see: Recommendations 4-5, 4-24, 5-12, 6-7, 8-6, 9-8].

Rationale

It is possible to design roadside CMS messages and in-vehicle messages in such a way as to influence the number of motorists who divert to an alternative route (e.g., Dudek, 2003). A critical factor for controlling the number of motorists who divert may be the amount and specificity of information presented about delays and travel times (Lerner, Huey, & Harpster, 1999; Lerner & Llaneras, 2000; Llaneras, Lerner, Huey, & Bensur, 1999). A route guidance system that is designed primarily to minimize individual personal travel time may have the unintended consequence of increasing congestion on alternate routes, possibly increasing safety risks and reducing the overall efficiency of the transportation system. Traffic management systems and vehicle guidance systems that operate under the same set of consensus standards could be coordinated to provide a balance between the needs of individual roadway users, including emergency vehicles and transit vehicles, with the need for overall network efficiency. As standards for coordination between in-vehicle systems and infrastructure-based systems are developed, opportunities for public education and public comment may be helpful for reducing driver frustration and misunderstandings about the new technologies. Greater levels of acceptance and satisfaction may be achieved by helping motorists adopt valid mental models about how such systems operate and by considering their concerns during the design process.

Recommendation 9-8: Standardize CMS messages for dynamic route guidance so that they have a consistent format with other CMS messages to motorists

The following informational elements (AND EXAMPLES) given below are common to many types of CMS messages and should be considered when designing messages to convey route guidance information in advance of an HRI. Because of limitations on the amount of information that drivers can read and process while approaching the CMS (see Chapter 5), usually only a subset of the elements can be displayed; however, depending on the HRI condition to be reported, not all elements may be needed.

- *Descriptor of HRI condition.* (TRAIN; FOG AT RR CROSSING; GATE MALFUNCTION, VEHICLE STALLED ON TRACKS, TRAIN ACCIDENT)
- *Location.* (1/2 MILE, PAST MAIN ST, AT CLOVER)
- *Effect on travel.* (15 MINUTE DELAY; NO THROUGH TRAFFIC; MAJOR DELAY; LANES REOPEN IN 5 MINUTES)
- *Audience for action.* (LOW TRUCKS, ORLANDO, DOWNTOWN TRAFFIC)
- *Action.* (REDUCE SPEED; LOOK FOR TRAINS; PREPARE TO STOP; USE OTHER ROUTES; USE ROUTE 18 SOUTH; USE OVERPASS ON SOUTH ST)
- *Good reason for following the action.* (SAVE 9 MIN; AVOID 15 MIN DELAY; AVOID COLLISION)

Although not all elements may be used in each message, the order of the elements should be preserved to maintain consistency with other CMS messages [Also see: Recommendations 4-5, 4-24, 5-12, 6-7, 8-6, 9-7].

Rationale

The message elements and element presentation order given above have been adapted from those proposed by Dudek (2003) as elements of the base message for incident and work zone messages presented on CMS. A consistent set of message elements and consistent ordering of elements support driver expectancies that may result in better driver performance.

Recommendation 9-9: Route guidance concerning the HRI should be based upon the most current and complete information available

To avoid diverting motorists to routes that end up being less favorable than the present route, recommendations to use an alternative route should be based on the best information possible. As ITS capabilities develop, such information may include current traffic flow and road conditions on the alternative route or, if that is not available, historical traffic volume data (for the current time of day and day of week), predictions about the number of vehicles expected to divert, predictions about the expected time until the original route is open (whether the HRI is blocked because a train is moving through the intersection, a train is performing a switching maneuver, or an incident has occurred that has closed the HRI, etc.). Information about the direction and speed of all trains in the vicinity should also be considered with respect to the alternative route guidance plan. For example, motorists should not be diverted from their present route to avoid a delay caused by a train traveling through the HRI if the diversion takes them to another HRI where a second train is approaching. Physical characteristics of the alternative route and the driver's vehicle should also be considered. Large trucks should not be diverted through underpasses that are too low, over bridges with low-weight restrictions, or through narrow city streets that require sharp turns [Also see: Recommendations 4-8, 8-12].

Rationale

Motorists who choose to follow an alternative route that actually turns out to be less efficient than their original route in terms of travel time may not be upset by small differences. In fact, research using realistically simulated trips found that drivers were confident that they had made the best route choice, even when they chose inefficient routes (Llaneras et al., 1999). On the other hand, drivers have an interest in knowing if they made the correct choice (Wenger et al., 1990; Khattak et al., 1991); if it is obvious that the recommended alternative route is inferior in terms of travel time, or because of conflicts like those mentioned above, they may become frustrated and lose confidence in the system. Therefore, it is important for algorithms that provide alternative routing information near the HRI to incorporate many sources of information on both fixed and transient local roadway and rail conditions so that routing information and guidance is as accurate as possible.

Recommendation 9-10: Provide motorists with dynamic route guidance information that incorporates predicted as well as current conditions at the HRI

For real-time in-vehicle systems and for Web-based or other pre-trip route planning systems, predictions about the status of an HRI as far as 15–20 minutes in advance may be useful for approaching motorists, especially where train schedules are regular or where alternative routes across the railroad right-of-way are far from the intended route. Re-routing motorists across train tracks to avoid a predicted HRI-related delay upstream on the planned route may be considered, but in all cases safety of the motorist should take precedence over potential reductions in trip time.

Rationale

With ITS technologies such as GPS, it may be feasible to track train movements far in advance of the HRI. Drivers may be more willing to change routes if a projected status is available, particularly if there is some indication given of the confidence level of the prediction. Based on experimental findings (Lerner & Steinberg, 2000), projections of about 15–20 minutes ahead are compatible with typical commuter trips, and the combination of current status and projected status provides adequate decision support for most commuter trips (Khattak, Schofer, & Koppelman, 1993). Conditions at HRIs due to the presence of a train or other incidents may change quickly; therefore, it is essential that predictions are updated frequently.

Recommendation 9-11: Support the driver's navigational decisions by providing all relevant information about the HRI in advance of route diversion points

Other information about the HRI that is unlikely to affect routing decisions may be presented to the driver after he/she has passed the route diversion point.

Rationale

If a condition exists at the HRI that may give the driver a reason to divert to an alternative route, the driver must receive this information early enough to have time to process the information, make a decision to divert (or not), and safely maneuver to the alternative route before it has been passed. Lerner and Llaneras (2000) have summarized the general issue in this way:

> Drivers want to receive traffic information [. . .] at locations where decisions can be made with respect to alternative routes (Dudek et al., 1971; Lerner & Steinberg, 2000). Usually, if advice is not followed, most often it is because it is given too late (Bonsall & Joint, 1991). The point in time during the journey at which the driver receives information regarding the route and traffic conditions affects the probability that the driver will divert to an alternative route (Allen et al., 1991; Khattak et al., 1991). Therefore, information should be communicated while opportunities to divert still exist.

[Also see: Recommendation 4-11]

Recommendation 9-12: Provide a driver-oriented reason when an alternative route is recommended to divert around the HRI

In many cases, the primary reason to divert to an alternative route will be to reduce travel time.

Rationale

Different drivers have different motivations and different preferences regarding reasons that they would elect to divert to an alternative route. As long as route choice remains the driver's decision, any recommendation to divert to another route should be accompanied by some rationale that the driver may consider in making a route choice. For information presented on a CMS, Dudek (2003) has described this message element as the "good reason for following the action." One important reason for diverting to another route is to reduce travel time. Lerner and Llaneras (2000) have noted that "numerous studies of driver decisionmaking as well as efforts to quantitatively model actual trip-making (Mahmassani & Liu, 1996; Aty & Jovanis, 1997) agree in finding that trip time is the dominant factor in route selection." A secondary preference factor that may influence route recommendations is roadway function class, where, in general, drivers prefer higher class roadways; however, for urban commuters some bias may exist to avoid extended freeway trips (Aty & Jovanis, 1997). Lower path complexity, clearly designated routes (e.g., marked with route numbers), lower traffic density and level of traffic interaction, fewer traffic signals, fewer turns, and lower costs also tend to be preferred by drivers (Khattak et al., 1991; Lerner & Llaneras, 2000). For some drivers, the secondary factors may be sufficient reasons to divert to an alternative route.

Recommendation 9-13: If an alternate route is recommended instead of the primary route across the HRI (driver's typical route or normal best choice route), provide an estimate of travel time on the alternative route

Rationale

Lerner & Llaneras, 2000 previously made this recommendation. When drivers are given guidance to take an alternative route, the estimated trip time becomes a key piece of information that they wish to know (Lerner, Huey, & Harpster, 1999). Drivers will be more likely to comply with the route guidance if the estimated trip time is included and accurate; however, it may be preferable to design travel time estimation algorithms with a slight bias toward overestimating trip times so that underestimates occur less frequently than overestimates. This is because commuters are less tolerant of underestimates than overestimated times (Mahmassani & Liu, 1996).

Recommendation 9-14: Emphasize quantitative information over qualitative information when expressing delays associated with the HRI

Rationale

For delays associated with traffic incidents, people generally prefer quantitative indications (e.g., 12-minute delay) more than qualitative statements (e.g., moderate delay) (Lerner, Huey, Zador, Duncan, & Harpster, 1998; Llaneras et al., 1999). Providing temporal information, such as delay time or travel time, is one of the most important factors influencing route choice (Lerner, Huey, Zador, Duncan, & Harpster, 1998). Quantitative information about traffic delays yields higher diversion rates than qualitative information alone (Khattak, Kanafani, & Colletter, 1994).

Recommendation 9-15: Recommend alternative routes when opportunities for significantly reduced travel times exist, as defined by the driver's personal preferences or when emergency situations arise at the HRI

An alternative route recommendation should not be given unless that route is significantly better than the present route. At all other times, alternative route information should be available upon request, subject to applicable ATIS standards concerning system features that are appropriate for use in vehicles that are in motion. Lerner and Llaneras (2000) recommended certain threshold values for the amount of expected travel time savings necessary to suggest a diversion from a planned route. A general-use value for this threshold is 18 percent of the travel time remaining but not less than 1 minute. If user-specific preferences and conditions are known, the following threshold values are recommended:

- Drivers with a low tolerance for late arrival: 5 percent (if current route jeopardizes on-time arrival)
- Drivers who are unfamiliar with the area: 20 percent
- Drivers who have specified route criteria other than time (e.g. scenic, costs): 20-25 percent
- Where the estimated time on the alternative route is highly variable: 20–25 percent

Rationale

Following nonemergency advisories about adverse conditions at the HRI, alternative route information should be available to the driver upon request but should not be presented automatically, unless triggered by the motorist's preset criteria. Presenting information to drivers automatically when they do not expect it may contribute to driver distraction and information overload. Many drivers are likely to be annoyed by the automatic presentation of alternative routing information and advance information about the HRI that they have not specifically requested. They may even try to disable the system, perhaps while they are driving. Under certain circumstances, however, alternative route information may be relevant even to drivers who usually do not change routes. When emergency situations arise that require a change of route, motorists should be informed about alternative routes, perhaps in a coordinated way that best supports public safety.

Drivers who are already en route have a bias to stay on their current route, even when small travel time savings is possible on other routes. Only when the travel time savings becomes sufficiently large will drivers divert to an alternate route. While little empirical evidence exists to quantify the threshold values given above, these are best estimates from the existing data (Lerner & Llaneras, 2000).

9.3.3 User Control

Recommendation 9-16: Give the user control over the types of advance information about the HRI that will be presented in-vehicle and the conditions that will trigger recommendations for selecting alternative routes

In-vehicle systems should allow users to tailor the operation of the system to their preferences. Although many types of advance information about the HRI may be available, consider providing user options to suppress information that is not desired. In addition, algorithms should trigger recommendations about alternative routes that incorporate individual driver preferences.

Rationale

Motorists will have different needs regarding advance information about HRIs and route guidance. If certain aspects of the system are annoying, distracting, or do not meet the user's needs, the system may be completely disabled. By user configuration options, however, the motorist's sense of control, and the information provided may be more useful, making it more likely that he or she will use the system. Drivers are likely to be more satisfied with (and follow the advice given by) an in-vehicle system in which route diversion recommendations reflect their own personal decision criteria. Lerner & Llaneras, 2000 gave a similar rationale for customized route diversion systems. In that study, personal characteristics related to the use of traffic information were age, gender, spatial ability, education level, and local familiarity with the roads.

Several reasons exist as to why the information needed by one driver approaching the HRI may differ from that needed by another. Drivers who are in a familiar area where they frequently travel may not want to receive alerts about the mere presence of a downstream HRI, while drivers who are traveling in an unfamiliar area, perhaps at night, may want to be alerted to the presence of HRIs. Drivers who are very concerned about reducing their travel times may appreciate automatic alternative route recommendations that save them only a few minutes, while other drivers may prefer to receive route guidance only upon request or, for example, when the expected travel time advantage of an alternative route exceeds a limit that they set, such as 5 minutes.

Table 13 lists several hypothetical drivers along with categories of HRI information that may be most useful to them. The categories given include the following types of information:

- *HRI ahead.* Distance, name of road that intersects tracks
- *Train approaching.* Estimated time until HRI is blocked, time until HRI is clear, train type, multiple trains approaching
- *Fixed features at HRI.* Unusual crossing geometry, no gates, number of tracks
- *Transient conditions at HRI.* Ice, gates malfunctioning, traffic backups, construction, or maintenance work in progress
- *Alternative routing recommendations.* Automatic or on-demand routing guidance to avoid delays, hazardous conditions, or to match user route preferences

These information categories are not specific recommendations for system design. Table 13 is meant only as an illustration of the potential differences in information needs of different roadway users. Real drivers may choose to receive different combinations of HRI information on in-vehicle displays than those shown.

Table 13. Information needed by drivers in advance of the HRI

Driver	Types of Information Needed in Advance of HRI				
	HRI Ahead	**Train Approaching HRI**	**HRI Fixed Features**	**HRI Transient Conditions**	**Alternative Routing Recommendations**
Urban Commuter	No (Familiar with all HRIs in area)	Yes	No (Familiar with all HRIs encountered. Conventional roadway signage is sufficient.)	Yes	Yes (May want to minimize travel time and travel time variability)
Small Town Residents	No (Familiar with all HRIs in area)	Yes	No (Familiar with all HRIs encountered. Conventional roadway signage is sufficient.)	Yes	No (Knows alternative routes and little benefit of re-routing exists)
Delivery Truck Driver	Yes (May be driving in unfamiliar area)	Yes	Yes	Yes	Yes (May want to minimize travel time, may be unfamiliar with area)
Tourist	Yes (May be driving in unfamiliar area)	Yes	Yes	Yes	Yes (Unfamiliar with area)
School Bus Driver	Yes (Required to stop at all HRIs)	Yes	Yes (Driver is familiar with route, but additional information may improve safety.)	Yes	No (Must follow a fixed route)

10. Enforcement and Control of Vehicles

Originally, these guidelines were to include a chapter to provide human factors guidance for ITS applications that deal with enforcement or direct vehicle control at the HRI. In reviewing the technologies and issues, however, it became apparent that neither direct intervention in vehicle control nor automated enforcement applications provide meaningful ITS human factors guidance needs at this point.

10.1 Control of Vehicles

If an errant vehicle is on a course to enter the HRI when a train is in hazardous proximity, it may be possible to intervene directly and prevent the vehicle from reaching the point of conflict. Such intervention could take two forms. One approach is to provide an infrastructure-based barrier between the vehicle and the train dynamic envelope. The other approach is to directly intervene in vehicle operation (braking or throttle) through telematic control.

None of the physical barrier systems deployed or under serious consideration appear to involve intelligent control of barrier deployment. Rather, the barrier is always activated when a train is approaching, as an additional element of a normally gated system (see Chapter 3). Therefore, this is not an ITS application. No intelligent application of the barrier occurs. Although it is conceivable that an active barrier could be designed to deploy only when an errant vehicle is sensed, this does not appear to be evolving, and it is not clear what, if any, human factors issues might be involved in deployment other than informing road users about the presence of the device. Obviously a major challenge in developing an intelligently deployed barrier would be to reliably detect and define threat situations in a manner that allowed enough time and distance to stop vehicles of various sizes and to do so without causing frequent nuisance deployments and without causing injuries from nontrain collisions (collision with barrier, collision with another vehicle, run off road). Deployment of the VAB for minor crossing violations is likely to result in frequent capture of vehicles that were not in danger of colliding with trains. At the other extreme, if only very late, major infractions activate the barrier, drivers may perceive that minor infractions are acceptable, and the rate of minor violations may increase.

Motorists' reactions to VAB deployment would be an important area for study. VABs, if implemented at HRIs, would be novel systems, and vehicle capture events should be rare. Therefore, drivers who are captured (or about to be captured) are likely to be surprised and confused. Driver confusion may result in any of a variety of reactions before and during contact with the VAB, including attempting to accelerate, brake, turn, or not reacting at all. Once the vehicle is brought to a stop, drivers may be confused, embarrassed, frightened, or panicked. They may worry about injuries to themselves or passengers, damage to the vehicle, their distance from the approaching train, or the possibilities of blocking traffic or receiving a traffic citation. In their confusion, they may take unsafe actions, such as attempting to accelerate through the VAB or reversing hastily and risking a collision with queued traffic.

Drivers who strike the VAB are not the only ones whose reaction must be considered. VAB deployment would also affect surrounding drivers. If a vehicle strikes a VAB, the path of following vehicles will be obstructed until it is retracted. Drivers may attempt to turn around or even attempt to cross the tracks using opposing lanes (if the deployed VAB does not span the entire roadway) or by leaving the roadway, which may be very hazardous.

If intelligent barrier systems are developed, it will be necessary to investigate the many potential effects on driver behavior and the overall implications for roadway safety. At this point, however, little indication exists for how such systems might operate.

No serious consideration of direct intervention in vehicle emergency control at rail crossings appears to exist, and, in fact, opinions the project team have received in discussions with government, industry, and research experts has discouraged this concept. There appears to be little support in the United States for such intervention across the span of ITS applications, not just HRIs. There has been ITS research activity related to infrastructure-based control of vehicle speed and path on automated highway lanes (e.g., Bishop, 2001). This is a case, however, where the driver voluntarily cedes normal control to the intelligent system, not a case where the system intervenes automatically in a potential crash situation. Furthermore, the interest has primarily been in improving roadway capacity rather than vehicle safety. Visions of the automated highway system have been reduced in terms of scale, degree of intervention, and timetable (Bishop, 2001). Considerable work has occurred on vehicle-based crash avoidance warnings (e.g., National Highway Traffic Safety Administration, 2002), especially for various vehicle-vehicle crash scenarios (e.g., forward collision warning), lane keeping, and road departure. In addition to not being directly relevant to vehicle-train crash scenarios, however, the development of this area has clearly focused on warnings, as opposed to autonomous braking or steering. Perhaps the most relevant parallel in the area of ITS development for roadway applications is the area of roadway intersection collision warnings. Here the infrastructure (independently or cooperatively with vehicle-based systems) must detect a threat from vehicles traveling on conflicting (roadway) paths and intervene in a timely way to help avoid a collision. In discussing this program area with FHWA staff, it is again clear that direct intervention in dynamic control of vehicles in traffic is not the current strategy. Thus, although it is technically conceivable that an ITS application could directly brake or steer an errant vehicle at an HRI, the clear consensus in both roadway and highway-rail communities at this time is that this is not the recommended approach. Overall, very significant safety and policy concerns regarding direct intervention in vehicle emergency control, and no mature or evident emerging systems exist. Such systems would also require cooperative technologies in the vehicle. Support for such systems does not appear to exist in the HRI area in the foreseeable future. A great many unknowns exist regarding the potential safety and human factors issues for such HRI systems. Therefore, the most reasonable guidance is that direct infrastructure control of braking or steering at the HRI is not recommended without a more substantial research base.

Thus at this time it does not appear warranted to propose human factors guidance for either intelligent barriers or systems that intervene directly in vehicle control. Barrier systems investigated to date do not have intelligent deployment and are not ITS applications.

10.2 Automated Enforcement

Automated enforcement is a means of applying intelligent sensing of vehicle actions to detect violators and identify them (by recording license plates, and sometimes images of drivers) for traffic citation. Automated enforcement of traffic signal violations at roadway intersections is increasingly common in the United States, though it remains controversial and is not as widespread as in Europe and Australia. Because enforcement of violations at HRIs is difficult and usually quite limited, automated enforcement would appear to be a promising approach.[13] As indicated in Chapter 3, however, automated enforcement at HRIs has not been adopted for wide-scale deployment in any jurisdiction, although several field demonstrations do exist, suggesting that it may reduce illegal track crossings.

Although automated enforcement is an ITS application, few requirements for human factors guidance exist. The major issues for greater deployment are technological (reliable detection and vehicle recognition), legislative, judicial, and societal (e.g., Blackburn & Gilbert, 1995). A recent set of operational guidelines for red light camera systems (Federal Highway Administration & National Highway Traffic Safety Administration, 2005) emphasizes the need for public education and warning signs to alert motorists that cameras are in use. Although some human factors issues related to automated enforcement may exist, it is not clear if any of these are unique to the HRI application. Furthermore, even for the roadway intersection application, little basis exists on which to provide such guidance. In a major review of red light camera enforcement, McGee and Eccles (2003) concluded that "to date, there have not been any research and effectiveness evaluations conducted to address or answer the question of what factors related to the intersection design or operations, the use of warning signs, the level of fines, or any public outreach, have on observed crash changes." One human factors question of interest is in how to use signage to most effectively influence driver behavior. This question must be addressed on both a specific-crossing and systemwide basis. McGee and Eccles discuss the alternatives of posting warning signs at camera-equipped sites versus systemwide signing but no good basis exists for recommendations, even for the highway intersection case. Thus, at this point, human factors guidance does not exist regarding automated enforcement at the HRI.

[13] One reviewer expressed the view that automated enforcement will not be successful if the traffic and train control system does not "make sense" to the road user. If the crossing system is not meaningful or trains are likely to block crossings for extended periods, cameras will not change motorist behavior. This reviewer further argued that traffic control practices with poor credibility for the driver (e.g., certain speed limits or stop signs at grade crossings) "may be teaching the motorist that the devices are not of real value."

11. Light Rail Transit

11.1 Background

The emphasis of this chapter is on issues that are unique to, or particularly relevant for, the highway-LRT intersection. Many of the human factors problems for highway-LRT intersections are similar as those for conventional HRIs; therefore, readers interested in LRT should also consult the relevant sections in the rest of this document. Chapter 3 and Chapter 9 discuss MTWs for LRT, and Chapter 9 gives general guidance about train arrival warnings. Chapter 7 discusses displays for pedestrians. Other sources of information on safety at highway-LRT intersections also may be helpful (Korve et al., 1996; Coifman & Bertini, 1997; Transit Cooperative Research Program, 1999; Farran, 2000; Siques, 2001, 2002).

LRT facilities are found in urban and suburban areas where highway-LRT intersections have a large volume of crossing traffic and a greater variety of roadway users than is found at a typical HRI on a conventional railroad. Various types of track alignments have been used to integrate LRT systems into cities, and these usually result in a close proximity between LRT tracks and roadways (Korve et al., 1996). In fact, light rail vehicles (LRVs) often operate on semi-exclusive or shared LRV right-of-way with motor vehicles, creating the need for integration of rail traffic control systems and highway traffic control systems. As traffic volumes on roadway systems grow, increasingly sophisticated levels of cooperation between highway and rail signal systems may be implemented to alleviate congestion and prevent gridlock. One form of cooperation between systems allows LRVs to pass through signalized highway intersections without waiting, by preempting the traffic signals at these points.

Traffic signal preemption refers to “the transfer of the normal operation of a traffic signal to a special control mode for the purpose of serving special vehicles or for other tasks that require termination of the normal traffic control” (Obenberger & Collura, 2001). When a signalized highway intersection is located near an HRI, the effects of control activities at one location can affect the other, with potential safety consequences. For example, downstream of the highway-LRT intersection signalized intersections may cause traffic queues to back up across the tracks. Additionally, roadway traffic waiting for an LRV to clear the HRI may queue up for a considerable distance, blocking roadway intersections upstream of the highway-LRT intersection. Traffic signal preemption is not in itself viewed as an ITS application unique to HRI, so the general issue of preemption is not included as a separate chapter in this report. ITS technologies, however, may provide opportunities to improve preemption implementations. Advance preemption algorithms will likely require LRV detection further in advance of the HRI and ITS technologies, such as GPS, which may play an important role in specifying and coordinating train movements. Although advance preemption strategies may be implemented at signalized intersections near conventional railroad crossings, the topic is included this chapter because preemption is used extensively at and near highway-LRT intersections.

Highway-LRT intersections are usually found in visually complex metropolitan environments that contain many TCDs, advertising signs, buildings, complex roadway geometry, and high volumes of vehicular and pedestrian traffic. Large vehicles, such as buses and delivery trucks, may block the motorist’s view of the roadway ahead, behind, or to either side. All of this visual complexity makes it difficult to recognize highway-LRT intersections and to detect approaching LRVs.

Visibility of LRVs may also be a problem for bicyclists and pedestrians, especially at crossings adjacent to light rail stations. The cognitive demands due to motor vehicle traffic, advertising displays, and crowds make it more likely that pedestrians will not notice an approaching LRV. Other pedestrians who may be visiting the particular city for the first time may not be familiar with the operational characteristics of LRVs or the risks that they present (also see Chapter 7).

Highway-LRT intersections are often located close to, or are part of, existing highway-highway intersections, and, in the environments where they exist, it may be difficult for approaching motorists to distinguish which intersections have LRT cross traffic. As a consequence, the motorist's expectations of events at these intersections may be more appropriate for a standard highway-highway intersection, and these false expectations can lead to dangerous behaviors, such as turning in front of an approaching LRV.

11.2 Key Human Factors Issues and Need for Guidance

11.2.1 Issue: Conspicuity of Highway-LRT Intersections and LRVs in Highly Complex Urban Environments

Highway-LRT intersections often appear to be standard highway-highway intersections to the roadway user, and LRVs tend to be less conspicuous than conventional trains. They are smaller and much quieter, and they travel in environments where they may be masked by noise and visual clutter. In addition, because LRT tracks often run along medians or on other right-of-ways that are parallel to the roadway, LRVs and highway vehicles are often oriented in the same direction. This makes LRVs much less conspicuous to parallel traffic. The LRV profile is smaller when seen head-on, and the LRVs are especially difficult to detect when approaching a driver from behind. The lack of conspicuity presents a problem for motorists and nonmotorized roadway users.

11.2.2 Issue: Conflicting Needs of Different Roadway Users at the Highway-LRT Intersection

The typical urban environment for highway-LRT intersections is likely to have a wide variety of different roadway users and types of vehicles that are not commonly found at standard HRIs located outside of urban centers. Besides automobiles, roadway traffic at highway-LRT intersections is likely to include many taxi-cabs, buses, long limousines with low-ground clearance, and several types of straight trucks used for deliveries. All of these urban vehicles have a tendency to double-park, which can further obscure the visibility of LRVs. Other users of the highway-LRT intersection may include motorized scooters, bicycle couriers, street vendors with push carts, and possibly even horse-drawn vehicles (e.g., Hansom cabs).

Large numbers of pedestrians, including those who have sensory, cognitive, or physical disabilities, may cross the highway-LRT intersection as well. All of these users share the need to detect LRVs and to know when it is safe for them to cross the intersection; however, in some cases, the needs of one group may conflict with the needs of another group. For example, wheelchair users require smooth ramps and continuous surfaces, while pedestrians who are visually impaired may prefer the unambiguous tactile boundaries provided by curbs. Similarly, auditory signals at the highway-LRT intersection may be essential for pedestrians with visual impairments, but ineffective for motor vehicle operators, and possibly annoying to local roadway users who have businesses or residences near the intersection. ITS technologies may enable warnings to be tailored for different roadway users. For example, in-vehicle displays could present warnings to heavy truck operators about limited storage space downstream of the LRT tracks.

11.2.3 Issue: Traffic Congestion Near the Highway-LRT Intersection and Preemption of Traffic Signals

The primary objective of preemptive control is to clear conflicting traffic from the HRI before the train's arrival. This may introduce conflicts for roadway users. For example, pedestrian crossing phases may be abruptly terminated, and pedestrians in the process of crossing the highway intersection may be in conflict with vehicles clearing the area. Other conflicts arise when multiple LRVs in close proximity preempt the traffic signals at a shared intersection. Multiple preemptions may cause some phases of the traffic signal cycle to be minimized or skipped entirely. This is particularly dangerous when the protected left turn phase is skipped. Impatient motorists, thinking that the signal is malfunctioning, may proceed against the signal and turn left into the path of an approaching LRV.

The criteria for preemption and the determination of the most effective procedures at highway-LRT intersections and conventional HRIs are complex issues that preclude simple guidance. In developing its guidance on recommended practice for preemption of traffic signals near railroad grade crossings with active warning devices, the Institute of Transportation Engineers (1997) stated that

> Preemption of traffic signals for railroad operations is very complex and must be designed and operated for a specific location, often with unique conditions. With the extremely large number of variables involved, it is difficult [. . .] to simply quantify time or distance components.

One of the difficulties in preemption is that it typically relies on the same circuitry as that used for train detection for control of the rail crossing signals and gates. This means that typically about 20 to 30 seconds of advance time exists in which to implement the preemption strategy and clear the conflicting traffic. Advance preemption (starting highway signal preemption sequences before activation of railroad warning devices) can be achieved by adding earlier train detection points. This can establish a clearance phase to reduce traffic cues downstream from the HRI. Sometimes very long track circuits are required to achieve the necessary amount of advance train detection time to implement complex advance preemption strategies. ITS technologies, however, offer greater opportunities to detect trains in advance, estimate arrival times, and implement more effective and less disruptive preemption methods. Venglar, Jacobson, and Engelbrecht (2000) discuss these techniques and their possibilities, and Korve et al. (2001) discuss many of the technical issues for implementing LRT preemption or advance preemption.

11.2.4 Issue: Conflicts for Motorists Turning in Front of LRVs

Vehicles turning in front of LRVs is one of the most common causes of collisions at signalized highway-LRT intersections. Farran (2000) has provided the following summary of conditions where these turning collisions occur:

- Motorists make illegal left turns across the LRT right-of-way immediately after termination of their green left-turn signal. They know it will still take a few seconds for the parallel traffic to enter the intersection from their stopped position; however, they are unaware that an LRV is rapidly approaching the intersection, typically from behind.

- Motorists violate the left-turn signal when leading left-turn indications to proceed are preempted (eliminated) by an approaching LRV. Usually, this illegal movement is not a conscious choice on the part of the motorist, who has simply learned to expect the green turn indication before the through movement.
- Motorists waiting to turn left across the LRT tracks become impatient as a result of red time extensions resulting from multiple LRV preemptions and illegally turn across the LRT right-of-way in the belief that the signal is malfunctioning. This type of accident is most likely to occur when the traffic signal does not recover to the left-turn movement after the LRV has cleared the intersection.
- Motorists violate active No Left/Right Turn (R3-2/R3-1) signs at signalized intersections with permissive turns (i.e., without an exclusive turn signal indication).
- Motorists violate a right-turn signal indication activated by an approaching LRV because they do not sufficiently know the vehicle code. Most motorists fail to recognize that it is not possible to turn right on red whenever a red right-turn signal indication (i.e., red turn arrow) is active.

A number of non-ITS countermeasures have been proposed for these problems (Farran, 2000; Korve et al., 2001), but this is an area where ITS-based countermeasures could also be effective.

11.2.5 Issue: Roadway Users' Understanding of Potential Hazards at the Highway-LRT Intersection and Compliance with TCDs

Roadway users may have misconceptions about the operation of LRVs and may not fully appreciate the risks involved in crossing the LRT tracks. For example, pedestrians may not understand that the LRV dynamic envelope extends beyond the boundary of the tracks, and they may stand too close, especially if other factors are at play, such as being unfamiliar with the area, being impaired by alcohol, or being at the front of a pressing crowd. Unlike motor vehicles such as buses, LRVs are generally not obligated to (and may not be able to) yield to pedestrians. This inconsistency may violate the expectations of some pedestrians who think that LRVs operate more like buses than trains. In addition, some pedestrians who tend to take the shortest possible path to reach their destination (even if this path involves trespassing along LRT right-of-ways or violates the geometry of established pedestrian pathways at the highway-LRT intersection) may not understand the level of risk associated with their actions. Other pedestrians, who do not have a driver's license, or who may not understand signs printed in English, may violate the directions given by TCDs because they do not understand either the meaning of the message or the appropriate response.

Motorists may also not fully appreciate the risks of violating TCDs, such as posted regulatory signs that prohibit driving on the LRT tracks, stopping on the tracks, making turns across the tracks, or passing a stopped train. ITS applications may be able to detect errant pedestrians and motorists and provide them with additional specific and more urgent warnings beyond the general regulatory and advisory signs designed to be seen by all roadway users.

11.3 Recommendations

Table 14 groups recommendations for LRT under two topics. Each topic includes individual recommendation statements.

Table 14. Recommendations for LRT

Uses of ITS applications at highway-LRT intersections
1. Use ITS applications for highway-LRT intersections when they fulfill a need or solve a problem that cannot be addressed as effectively by other technologies.
2. Use automated enforcement of vehicles at the highway-LRT intersection to deter hazardous behaviors.
3. Detect potential violators of left-turn prohibitions across LRT right-of way and warn them to stop.
4. Detect pedestrians who are standing in a hazardous location and warn them.
5. Supplement blank out signs that prohibit turns across the LRT right-of-way with an active indication that an LRV is approaching.
6. Use ITS technologies to enhance conspicuity of highway-LRT intersections and LRVs approaching the intersection.
7. Detect traffic queues and provide upstream active warnings against blocking the highway-LRT intersection.
8. Provide an in-vehicle indication of nearby LRV.
9. Provide an auditory warning at highway-LRT intersections for pedestrians.
Preemption of traffic signals by LRVs
10. Consider driver expectancies and behaviors when implementing ITS-based, advance preemption strategies at highway-LRT intersections.

11.3.1 Uses of ITS Applications at Highway-LRT Intersections

Recommendation 11-1: Use ITS applications for highway-LRT intersections when they fulfill a need or solve a problem that cannot be addressed as effectively by other technologies

The use of ITS technologies to improve safety at highway-LRT intersections should be considered after first exploring conventional countermeasures. Simple, relatively low-cost and low-maintenance solutions, such as passive gates, pedestrian channeling treatments, barriers, passive gates, and conventional signs, may often be effective as or more effective than technology-intensive solutions. Non-ITS technologies should continue to be developed and implemented wherever they are most effective [Also see: Recommendation 7-8].

Rationale

ITS-based systems that show promise when deployed sometimes prove to be less effective than conventional countermeasures. Additionally, a number of highly effective non-ITS strategies have been developed for improving the safety of pedestrians and motorists at highway-LRT intersections (Korve et al., 1996, 2001; Coifman & Bertini, 1997; Transit Cooperative Research Program, 1999; Farran, 2000; Siques, 2001). The implementation of ITS solutions should not be driven only by technical feasibility or by the false assumption that more sophisticated technologies will be more effective than conventional solutions.

Recommendation 11-2: Use automated enforcement of vehicles at the highway-LRT intersection to deter hazardous behaviors

Photo enforcement or other automated enforcement strategies can deter illegal left turns across tracks, driving around lowered gates, and driving on the LRT right-of-way. Wherever implemented, conventional signs should be posted at or near the highway-LRT intersection to inform drivers that automated enforcement is being used.

Rationale

Criteria for using automated enforcement at HRIs is still not well established (see Chapter 10). Photo enforcement, however, has been an effective tool for reducing the number of violations at some highway-LRT intersections. For example, LACMTA introduced a photo enforcement program at highway-LRT intersections in the 1990s. In this system, inductive loop detectors detected vehicles driving around the tip of a horizontal gate arm. Citations were issued based on a series of two photographs taken of the violating vehicle. This program reduced the number of crossing-gate violations by 92 percent and reducing the number of LRT-motor vehicle collisions by 70 percent (Korve et al., 2001). Posting signs that inform drivers that automated enforcement is in use may inhibit risky behaviors. Violators who may have a low perceived risk of being struck by an LRV may be deterred from engaging in risky, illegal crossing behaviors if they perceive that it is highly likely that they will receive a citation based on evidence from automated enforcement equipment. Automated enforcement provides another reason (besides the obvious danger) not to drive under or around gates, or to violate other traffic controls.

Recommendation 11-3: Detect potential violators of left-turn prohibitions across LRT right-of-way and warn them to stop

ITS technologies can detect vehicles likely to cross the tracks in front of an approaching LRV. Left-turning vehicles that pull forward (some distance) beyond the stop line as if to make a left turn could be detected, and an auditory warning could be issued during periods when left turns are prohibited (LRV approaching). An in-vehicle system or an audible wayside signal could deliver such a warning. An activated blank-out sign, collocated with the sound source, could also be used to deliver a message to the potential violator [Also see: Recommendation 4-13].

Rationale

One of the most common causes of LRT collisions is motorists making left turns across the tracks. Coifman & Bertini, (1997) recommended a warning for left-turning vehicles at highway-LRT intersections. Vehicles at highway-LRT intersections travel at relatively low speeds, particularly turning vehicles. Audible alarms are appropriate when the message calls for immediate action and when visual attention is otherwise engaged (McCormick & Sanders, 1982), as is the case for a driver making a left-turn maneuver. A wayside directional sound source(s) could be positioned close to the violating driver and would serve to stop the driver before entering the LRV dynamic envelope. If possible, the system should direct the violating driver’s attention toward the approaching LRV. In addition to alerting inattentive violating drivers about the hazard, a highly conspicuous auditory alarm may serve as a deterrent for drivers who knowingly violate the left-turn prohibition when the LRV is approaching. The auditory signal should be loud enough to be heard inside the violating vehicle and should make it obvious which vehicle triggered the alarm, calling attention to the violator. If local residents and business owners are annoyed by auditory signals, a highly conspicuous visual signal, such as a strobe, could be considered. Whether auditory or visual, the alarm should be activated only by vehicles in danger rather than by each approaching LRV.

Recommendation 11-4: Detect pedestrians who are standing in a hazardous location and warn them

An ITS system may detect and warn pedestrians who violate automatic gates or who stand too close to the tracks when an LRV is approaching. The system may detect pedestrians standing within the dynamic envelope of an approaching LRV and issue an urgent audible or visual warning. If possible, this warning message should (1) be directed in such a way that it is clear which pedestrian is in violation, (2) convey that the pedestrian is currently in a dangerous position, and (3) clearly indicate what action should be taken to avoid the hazard [Also see: Recommendations 4-13, 7-6].

Rationale

Despite the use of conventional pedestrian controls, such as gates, lights, signs, painted markings, and pavement treatments, various situations may arise where pedestrians violate these controls and end up within the hazard zone when an LRV is approaching. To handle these exceptional but dangerous situations, the passive or active crossing could have some controls that are reactive (Coifman & Bertini, 1997). Technology exists to detect the presence of pedestrians in specific locations, although the ITS applications under development on street crossings rather than rail crossings (e.g., Bechtel, Geyer, & Ragland, 2004). Activating a warning signal may be the last chance to capture the errant pedestrian's attention with enough time to escape from being hit by the approaching LRV. The warning should be directed at the pedestrian (or pedestrians) who are in danger so that the violators do not assume that someone else triggered the warning, and the nature of the violation and danger should be clearly conveyed so that the pedestrian does not assume that merely standing off the tracks is a sufficiently safe.

Recommendation 11-5: Supplement blank-out signs that prohibit turns across the LRT right-of-way with an active indication that an LRV is approaching

The LRT approaching-Activated Blank-Out (W10-7) warning sign or a similar active indication should be used along with transient Turn Prohibition signs at highway-LRT intersections. In-pavement lights installed at the HRI and visible to turning vehicles may also be used as an active indication that an LRV is approaching.

Rationale

Turn prohibition signs are active only when an LRV is near, so drivers usually encounter the signs in the blanked-out state and are permitted to make turns across the tracks. An activated turn prohibition sign directly controls a driver's behavior on only a small percentage of approaches to the intersection. (In fact, the sign only directly controls the first driver in the turning queue; the movement of other vehicles in the turn queue is restricted by vehicles blocking the way ahead of them.) This means that drivers have relatively little experience restricting their turn movements based on the turn prohibition signs. As a result, their normal visual scanning patterns, expectations, and habitual behaviors preceding the turning maneuver may lead them to proceed, unknowingly in violation of the turn prohibition.

Where transient turn prohibitions across LRT tracks are in effect, the supplemental LRT Approaching (W10-7) warning sign can provide motorists with rationale for the activated turn prohibitions and an indication of the hazard associated with violating the turn prohibition. Where the LRV preempts the traffic signal, the W10-7 sign notifies motorists that the left-turn phase is delayed because an LRV is approaching and not because the traffic detector circuit or some other part of the signal system has failed. If it is located near the Activated Blank-Out Turn Prohibition Sign (R3-1a, R3-2a), the LRV Approaching sign may enhance conspicuity and comprehension of the overall message. Alternatively, the LRT Approaching warning sign may be more effective if it is installed close to the turning driver's line of sight, which may be relatively low for drivers who are scanning for gaps in traffic to make their turn. In-pavement lights may also be effective because they may be closer to the turning driver's line of sight than the turn prohibition sign, which typically would be mounted above the roadway.

Recommendation 11-6: Use ITS technologies to enhance conspicuity of highway-LRT intersections and LRVs approaching the intersection

Conspicuity of LRVs is most important when they are approaching a highway-LRT intersection. The general recommendation is to use ITS technology to coordinate dynamic conspicuity enhancements between approaching LRVs and highway-LRT intersections. Strobe lights are one such enhancement that may be considered for use on the LRV and at the highway-LRT intersection. Auditory warnings are another [Also see: Recommendation 4-1].

Rationale

A recognized need exists for enhancing the conspicuity of LRVs, especially with regard to maximizing the front-end visual impact of the LRV (Korve, 1996). Enhanced conspicuity is needed at all points where potential conflicts exist between roadway users and LRVs, but not necessarily at other locations where the LRV may be stopped or moving through a track section configured in an exclusive LRT alignment. Due to the already high level of visual clutter in the urban environment, it may not be sufficient (or aesthetically desirable) to introduce static conspicuity enhancements, such as more vivid paint colors, to LRVs. Roadway users may habituate to static conspicuity enhancements, but dynamic enhancements, such as a flashing light, may maintain their effects over long periods of time. However, because dynamic elements, such as flashing lights are one of the strongest forms of conspicuity enhancement available to traffic engineers, they should be used sparingly to retain effectiveness. Therefore, dynamic enhancements should activate to attract attention to the LRV only when the greatest potential for conflict exists, such as when the LRV is approaching a highway-LRT intersection. For example, the combination of two coordinated strobes at the intersection and on the LRV may promote perceptual grouping of the approaching LRV and the highway-LRT intersection, and, if a slight delay separates the coordinated flashes, an apparent motion effect may be created, providing an additional visual cue to enhance conspicuity. Laboratory studies have found that apparent motion effects significantly improve sensitivity and reduce reaction times for targets presented on simulated in-vehicle displays (Cohn, 1996). Coordinated auditory signals from LRV and HRI could help compensate for the fact that LRVs may approach relatively quietly.

Recommendation 11-7: Detect traffic queues and provide upstream active warnings against blocking the highway-LRT intersection

Rationale

One such system implemented in Edmonton, Canada, detects queues forming downstream of LRT tracks. Before a traffic queue actually builds back far enough to block the tracks, the system activates beacons mounted on a fixed Do Not Block Crossing sign located immediately upstream of the HRI (Korve et al., 2001).

Recommendation 11-8: Provide an in-vehicle indication of nearby LRV

If a visual in-vehicle display is used, consider the Light Rail Approaching—Activated Blank-Out (W10-7) warning sign given in the MUTCD (Federal Highway Administration, 2003). Supplement the visual indication with an in-vehicle auditory alert.

Rationale

Although measures designed to improve the conspicuity of the LRVs may help roadway users approaching the highway-LRT intersection from the crossing direction, roadway users who are traveling parallel to the LRT tracks often encounter LRT vehicles that approach them from behind. An in-vehicle alert may act as a countermeasure for the problem of drivers turning in front of an overtaking LRV. If an icon is used on an in-vehicle display to represent an approaching LRV, it should be consistent with the roadside display. Chapter 6 and Chapter 9 give other guidance concerning in-vehicle displays and train arrival warnings.

Recommendation 11-9: Provide an auditory warning at highway-LRT intersections for pedestrians

Audio warning devices can help pedestrians who are visually impaired, especially at highway-LRT intersections where auditory warnings are not used because of noise concerns or at HRIs where vehicles are controlled by automatic gates, and auditory warnings are turned off once the gates descend to their horizontal position [Also see: Recommendations 7-4, 7-6].

Rationale

LRVs are much quieter than conventional locomotives, and other noises in the urban environment can mask their approach. LRT pedestrian facilities should be accessible and usable by all pedestrians, including those who have impaired vision. ITS technologies can provide advance auditory warnings about approaching LRVs, as well as an all clear release indication when it is safe for pedestrians to cross the tracks. Various types of small audio warning devices for pedestrians have been implemented in Sacramento, California, and Portland, Oregon (Korve et al., 2001). These devices can be much quieter than wayside bells because they can be located and directed very close to pedestrians.

11.3.2 Preemption of Traffic Signals by LRVs

Recommendation 11-10: Consider driver expectancies and behaviors when implementing ITS-based, advance preemption strategies at highway-LRT intersections

Many factors are considered when designing advance preemption strategies for highway-LRT intersections and nearby intersections; however, because of the large number of variables involved and the unique characteristics of each highway-LRT intersection, little universally applicable guidance or standards are available. Nevertheless, the following lists four guidance points concerning preemption that address human factors issues. The related human factors issues are explained in the rationale sections. Only some of these recommendations may be relevant for any particular highway-LRT intersection [Also see: Recommendations 4-7, 4-17].

Point 1

Consider programming the traffic signals at intersections located adjacent to LRT crossings so that the protected left turns (across the tracks) from the parallel street follow the parallel street through movements (this sequence is called lagging left turns). Then, when exiting from LRT preemption, recover to the lagging left-turn phase first before serving cross-street traffic, if this can be done without dangerously long traffic queues building up on the cross street (Transit Cooperative Research Program, 1999).

Rationale for Point 1

The most prevalent type of LRV-motor vehicle accident involves motor vehicles turning across the LRT tracks (Farran, 2000). Point 1 is meant as a countermeasure to avoid some of the collisions involving vehicles turning left from a parallel roadway across LRT tracks located in the median. At intersections where a leading left-turn indication is used (protected left phase precedes the through movement), motorists expectations are violated when LRV preemption eliminates the green left-arrow phase. In this case, the normal sequence of traffic movements is altered, and the motorist may begin to make a left turn as soon as the cross traffic is stopped, anticipating that he/she will have a green left arrow without realizing that his/her left-turn maneuver is now prohibited due to the approaching LRV. By changing the signal phase sequence to have a lagging left indication (green left arrow follows the through movement and precedes the cross-street movement), left-turning motorists cannot anticipate the left turn signal based on the behavior of the cross traffic. Some LRT systems have adopted the lagging left-turn sequence with noted reductions in accidents at the locations where the change was made (Korve et al., 1996; Farran, 2000).

The second part of Point 1, to recover from preemption sequence to the protected left-turn movement, addresses the problem that multiple LRV preemptions may violate the expectations of left-turning motorists. In these cases, the left-turn phase may not occur for multiple cycles, while some of the other traffic movements are allowed (e.g., through movement parallel to the tracks). This can lead impatient drivers to assume that the traffic signal is malfunctioning and to proceed across the tracks against the signal, without seeing that another LRV is approaching the intersection. When the preemption sequence is followed by the protected left-turn movement, impatient motorists can safely clear the intersection. Typically, if lagging left-turn sequence is used, the next movement to be served will be the through cross traffic, which may have a long queue. The ITE has supported this approach: "With frequent preemption (as with commuter rail or LRT operation), the traffic signal may be programmed to first service turn movements from the highway parallel to the track" (Institute of Transportation Engineers, 1997), as have several other authors (Korve et al., 1996; Farran, 2000; Korve et al., 2001).

Point 2

As an alternate preemption exit strategy, record the exact point in the signal cycle that was interrupted by preemption, and recover to that phase if only a small proportion of the phase time had been served before the preemption; or if most of the phase time had been served before preemption, recover to the next phase in the sequence (Transit Cooperative Research Program, 1999).

Rationale for Point 2

An alternative to always recovering to the same traffic movement following the preemption sequence is to recover to the movement that was eliminated by the preemption sequence. This reduces the wait time for drivers whose signal phase was interrupted and who have been waiting at the intersection the longest. This may reduce their perception that the traffic signal system is malfunctioning, which can lead to drivers violating the traffic control signals.

Point 3

For low-speed LRT systems where it is possible to stop the LRV regularly at highway intersections, and where multiple LRVs may approach the same intersection in closely spaced intervals, consider denying LRV preemption requests in some circumstances and make the LRV wait for their turn to proceed. For example, consider canceling all LRV preemption requests that occur within a short period of time (1 or 2 minutes) following the activation of a preemption cycle. In addition, consider granting preemption requests only from LRVs traveling in one direction at certain times of the day, such as the peak load direction during peak commute hours (Farran, 2000).

Rationale for Point 3

This purpose of this recommendation is to reduce the incidence of multiple LRV preemptions occurring close together in time. Because of the long wait times, drivers experiencing multiple LRT preemptions may lose confidence in the traffic signal system and think that it is malfunctioning. By reducing successive LRV preemptions, the operation of the traffic signals will more closely match drivers' expectations, and drivers may violate signals less frequently. Such restrictions on LRT preemption have been used in San Francisco and San Jose, California (Farran, 2000). In places where LRVs operate at speeds greater than 35 mph (55 km/h), it may be necessary to preempt traffic signals at certain highway-LRT intersections all the time.

Point 4

When using ITS technology to detect the approaching LRV far ahead of the intersection, account for changes in LRV speed by frequently updating the predicted arrival time at the HRI and making any necessary adjustments in the advance preemption traffic signal sequences or signal phase times, while preserving approximately constant warning times for active wayside controls.

Rationale for Point 4

To avoid conflicts between railroad active warnings and traffic signals, and to maintain roadways users' confidence in the traffic control system, it is necessary to coordinate railroad warning devices and highway traffic controls beyond the initial train detection notification. LRT wayside warning devices often incorporate the constant warning time principle, so the train speed is monitored, and warning activation onset time adjusts accordingly to provide an approximately constant amount of time between activation of the wayside warning devices (lights, gates) and arrival of the LRV at the HRI. The interconnected traffic signal controller, however, typically operates on a single early detection input from the rail system and does not have any opportunity to adjust to delays in activation of wayside warnings caused by a decelerating LRV. A condition known as preempt trap may occur when the green track-clearance phase of the preemption sequence terminates before the railroad warning devices activate (Venglar, Jacobson, Sunkari, Engelbrecht, & Urbanik, 2000; Korve et al., 2001). This circumstance violates motorists' expectations as they queue up across the tracks, unaware that an LRV is approaching, and they get trapped by the descending automatic gates. Some proposed solutions to preempt trap are to use longer track-clearance green times or to install a not-to-exceed timer that forces the activation of wayside warning devices (lights, gates) before the time that they would be activated by the railroad system for predicted train arrival at the HRI (Venglar et al., 2000). As ITS technologies produce longer advance preemption times (as may be needed for complex advance preemption strategies involving multiple traffic signals), systems may require more extensive communication between the rail system and traffic signal controllers, along with traffic controller algorithms that can intelligently adapt signal phase timings to better coordinate with the activation of wayside warning systems. Korve (1999) reached a similar conclusion:

> As more accurate train position information becomes available, traffic signal systems that are adjacent to highway-rail grade crossings could be equipped to accept more detailed data about train position, speed, and estimated time to crossing. With this data, the traffic signal controller would be able to accommodate train movements without the abrupt preemption process, improving highway-rail grade crossing safety and efficiency.

Smoother transitions between normal traffic signal sequences and preemption sequences may result from incorporating ITS technologies. One example of Venglar, Jacobson and Engelbrecht (2000) proposed a smoother preemption transition algorithm, called the Transitional Preemption Strategy. Improvements to current preemption practices at highway-LRT intersections could be more consistent with roadway users' expectations. Traffic signals may appear to operate more uniformly over time, providing a more consistent, predictable experience for roadway users at the highway-LRT intersection, whether an LRV is approaching or not.

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Appendix.
List of Recommendations

CHAPTER 4: MESSAGE FACTORS

Factors to ensure message is noticed

1. Ensure adequate conspicuity of the message.
2. Limit displays to needed messages.

Factors to improve comprehension of message

3. Ensure legibility and audibility under probable operating conditions.
4. Make the desired road user action explicit and unambiguous.
5. Use standard or common wording, abbreviations, images, and formats.
6. Test for road user comprehension.
7. Promote compatibility with the road user's mental model of how the system works.

Factors to improve credibility of message

8. Assure that information is accurate and timely.
9. Minimize the frequency of all categories of nonuseful alerts.
10. Consider road user perceptions about the motivations and criteria of traffic-rail authorities.

Factors to improve compliance with the message

11. Provide adequate response time, consistent operation, and controlled workload.
12. Avoid excessively conservative criteria.
13. Provide road user feedback regarding noncompliance and unsafe behaviors.

Distinguishing safety-critical messages

14. Design safety-critical messages to be immediately recognizable as urgent safety alerts and discriminable from other messages.

Choice of message display mode

15. Consider the advantages and disadvantages of alternative display modes.

Unintended consequences of the message

16. Avoid driver distraction.
17. Consider the potential effects of automation complacency and risk compensation (behavioral adaptation).
18. Minimize annoyance.
19. Anticipate road user misuse of information.

Message appropriateness for specific road users

20. Customize ITS messages for the current situation.
21. Devise messages for effective communication with non-English-literate road users.
22. Devise messages for effective communication with older road users.
23. Devise messages for effective communication with road users having disabilities.

System considerations

24. Provide uniform messages and displays across information sources and sites.
25. Provide compatible message timing among information sources.
26. Manage information demand and driver workload.
27. Integrate ITS functions.
28. Avoid the development of inappropriate road user expectancies about the roadway and railway network.
29. Integrate ITS HRI displays and controls with the roadway traffic control system.

CHAPTER 5: ROADSIDE DISPLAYS

Location of roadside signs

1. Locate roadside displays relative to the hazard or decision point.
2. Locate ITS roadside displays to avoid driver information overload.

Conspicuity and legibility of roadside displays

3. Make displays conspicuous but not overly distracting.
4. Use positive contrast orientation (legend lighter than background) for self-luminous roadside displays.
5. Keep luminance contrast of CMS between 8 and 12.
6. Adapt visual displays to ambient lighting.
7. Design displays for the visual acuity of licensed drivers.
8. Sequential (multiphase) messages may be used on CMS for non-crash avoidance messages, with certain constraints.
9. Limit message length for CMS displays.

Animation in roadside displays

10. Use animation selectively.

Ensuring that messages are understood

11. Follow a systematic message design process.
12. Use standardized words and symbols.
13. Use icons where appropriate.
14. Use color-coding selectively to enhance understanding.

In-pavement lights

15. Ensure that in-pavement warning lights, if used at the HRI, are installed and operated so that they are: (1) effective, (2) consistent with other TCDs at the HRI, and (3) consistent with other traffic control applications of in-pavement lights.

Nonvisual roadside displays

16. Use acoustic signals to supplement HRI roadway visual displays.
17. Consider using tactile signals at the HRI.

CHAPTER 6: IN-VEHICLE DISPLAYS

Choice of mode

1. Use visual displays to present spatially-based information and for long or complex messages (provided the vehicle is not in motion).
2. Use audible presentation modes for delivering high-priority information requiring immediate action.
3. Use speech-based messages when high degree of detail is required and the meaning of other sounds may be ambiguous or forgotten under stress.
4. Consider using visual icons rather than text-based messages.
5. Consider using auditory icons in place of tones or beeps.

Visual display attributes

6. Locate visual displays for warning systems within the driver’s field of view, without obstructing the driver’s view of the dash controls, gauges, or mirrors.
7. Use standardized icons and graphics for in-vehicle warnings.
8. Ensure that visual display elements (characters, text, graphics, etc.) are sufficiently large to be read in moving vehicles and that the information can be assimilated with a few brief glances.
9. Use some means to attract driver attention to the display (e.g., flashing lights) if the system relies exclusively on a visual display to communicate information (no audible warnings/messages).

Auditory (nonspeech) display attributes

10. Audible warnings should be sufficiently loud so they can be detected and understood by the driver in the presence of background noise.
11. Limit the number of different warning tones to three or four easily discriminable sounds.
12. Auditory alerts should be used to notify drivers of high-priority messages, changes in status, and to augment signage information.
13. Tonal signals (nonverbal auditory signals) should use a frequency range between 500 and 3000 Hz and burst durations of about 100 ms.

Speech display attributes

14. Avoid the use of synthetic speech displays.
15. Messages that require an immediate response should consist of a single word or short phrase, and they should be understood immediately.
16. Provide a means for repeating speech messages.
17. Ensure that messages are easily differentiated from other speech in vehicles.

User control and adjustment

18. Complex information and control interactions should not be designed for use in a moving vehicle.
19. If multiple input or adjustment controls are present, design the controls so drivers can easily differentiate among the controls and their functions.

Location of controls

20. Locate system controls within the driver's reach, with the most frequently used or accessed controls closer to the driver's line of sight and reach.
21. Match the type of control used to the types and levels of functions to be controlled.

Operational issues related to in-vehicle systems

22. At actively controlled crossings with gates, in-vehicle warnings should be timed (coordinated) with the activation of the crossing gates or other active warning devices.
23. Provide system compatibility and integration.
24. Indicate system status.
25. Tailor information presented within the vehicle to match the driver's specific situation and needs (e.g., approaching an HRI, waiting at an HRI, EMS, etc.)
26. Evaluate the potential effects of behavioral adaptation for new in-vehicle systems.

CHAPTER 7: DISPLAYS FOR PEDESTRIANS

Positioning the display

1. Install visual displays in locations that are consistent with pedestrians' expectations, close to the intended crosswalk, and within a 20-degree cone of the forward line of sight.
2. Ensure that warning displays are configured so that they are conspicuous for pedestrians who are in the process of crossing the tracks when a train warning is issued, as well as for pedestrians who are approaching the HRI.
3. Separate messages for motorist from messages for pedestrians.

Accessibility of the warning

4. Consider multiple modes of display when providing warnings or other information to pedestrians at the HRI.
5. Include pedestrians who have disabilities in the design and testing process for new display features.

Directed warnings

6. Consider providing a targeted last chance warning system for pedestrians who are in immediate danger.

Use of conventional pedestrian control devices

7. ITS displays for pedestrians should be used in conjunction with positive control devices, such as gates and barriers.

CHAPTER 8: WARNINGS ABOUT TRAIN ARRIVAL

Recommendations for Train Arrival Warnings

Information provision (what to communicate)

1. Display train-related information only if it fulfills a need.
2. Limit the amount of information presented.
3. Issue alerts about the presence of HRIs and warnings about the presence of trains.
4. Present integrated, directly usable information.
5. Design messages based upon information handling zones.
6. Provide standardized message content on CMS at the HRI.
7. Provide cues as to the direction of approaching trains.
8. Provide a release indication.

Signal characteristics (how to communicate)

9. Use CMS as a primary means to communicate HRI status.
10. Consider conspicuity enhancements for visual displays.
11. Avoid temporal countdown displays for motorists.
12. Provide accurate and reliable information.
13. Minimize nuisance warnings to drivers not in potential conflict.

Timing of signals for train arrival warnings

14. Issue warnings throughout the entire duration of the train event, but provide a way to reduce the nuisance potential of the warning.
15. Inform roadway users at HRIs where extended advance warning times are used.

Coordination with external controls

16. Coordinate ITS warnings and non-ITS traffic control devices.

Specific Recommendations for MTWs

Message content and message comprehension for MTWs

17. Use an active caution message.
18. Convey all important elements of the warning message either explicitly or implicitly.
19. Ensure complete message comprehension.
20. Present consistent behavioral cues during multiple train events.

Signal conspicuity for MTWs

21. Attract the attention of at-risk road users.
22. Enhance conspicuity with visual features.
23. Ensure that both text and graphic display elements are legible.
24. Supplement MTW displays with acoustic signals.

Message timing and phasing for MTWs

25. Initiate MTW before first train passes.
26. Limit the length of message phase times.

MTWs for drivers

27. Use the following components of MTW displays for motor vehicle traffic.
28. Install a roadway-based MTW display in a location appropriate for motor vehicle traffic.

MTWs for pedestrians

29. Provide an MTW to pedestrians at HRIs where more than one train often passes through the HRI in close proximity.
30. Use the following components of MTW displays for pedestrians.
31. Install an MTW display in a location appropriate for pedestrian traffic.

CHAPTER 9: ADVANCE INFORMATION ABOUT THE HRI AND DYNAMIC ROUTE GUIDANCE

Advance information about the HRI

1. Provide advance information about HRI status and characteristics subsequent to a general warning about the presence of the HRI, except where this conflicts with other criteria for message placement or timing.
2. For in-vehicle systems, include advance information about fixed features and hazards at the HRI that is typically conveyed by conventional roadside signs.
3. Provide motorists with additional advance information about transient conditions at the HRI, which is not typically conveyed by conventional roadside signs.
4. For advance information to motorists about potential hazards at the HRI, identify the hazard and advise the driver how to respond.
5. Provide advance information about the HRI only to roadway users for whom the information is relevant.
6. Distinguish between active and passive crossings when providing advance information about HRI location.

Route guidance

7. Develop consensus standards for providing dynamic route guidance through or around HRIs.
8. Standardize CMS messages for dynamic route guidance so that they have a consistent format with other CMS messages to motorists.

9. Route guidance concerning the HRI should be based on the most current and complete information available.
10. Provide motorists with dynamic route guidance information, which incorporates predicated, as well as current, conditions at the HRI.
11. Support the driver's navigational decisions by providing all relevant information about the HRI in advance of route diversion points.
12. Provide a driver-oriented reason when an alternative route is recommended to divert around the HRI.
13. If an alternate route is recommended over the primary route across the HRI (driver's typical route or normal best choice route), provide an estimate of travel time on the alternative route.
14. Emphasize quantitative information over qualitative information when expressing delays associated with the HRI.
15. Recommend alternative routes when opportunities for significantly reduced travel times exist as defined by the driver's personal preferences or when emergency situations arise at the HRI.

User control

16. Give the user control over the types of advance information about the HRI that will be presented in the vehicle, and the conditions that will trigger recommendations for selecting alternative routes.

CHAPTER 10: ENFORCEMENT AND CONTROL OF VEHICLES

Vehicle arresting barriers (VABs)
Automated enforcement (AE)

CHAPTER 11: LRT

Uses of ITS applications at highway-LRT intersections

1. Use ITS applications for highway-LRT intersections when they fulfill a need, or solve a problem that cannot be addressed as effectively by other technologies.
2. Use automated enforcement of vehicles at the highway-LRT intersection to deter hazardous behaviors.
3. Detect potential violators of left turn prohibitions across LRT right-of way and warn them to stop.
4. Detect pedestrians who are standing in a hazardous location and warn them.
5. Supplement blank out signs which prohibit turns across the LRT right-of-way with an active indication that an LRV is approaching.
6. Use ITS technologies to enhance conspicuity of highway-LRT intersections and LRVs approaching the intersection.
7. Detect traffic queues, and provide upstream active warnings against blocking the highway-LRT intersection.
8. Provide an in-vehicle indication of nearby LRV.
9. Provide an auditory warning at highway-LRT intersections for pedestrians.

Preemption of traffic signals by LRVs

10. Consider driver expectancies and behaviors when implementing ITS-based, advance preemption strategies at highway-LRT intersections.

Acronyms and Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
ADA	Americans with Disabilities Act
ATIS	advanced traveler information system
AWARD	Advance Warning to Avoid Railroad Delays
BNSF	Burlington Northern Santa Fe Railroad
CCS	Collision Countermeasure System
cd/m^2	candelas per square meter
CMS, CMSs	changeable message sign(s)
CWS	collision warning system
CWT	constant warning time
DB	decibel
DOT	Department of Transportation
EMS	emergency medical services
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GPS	Global Positioning System
GRIP	graphic route information panel
HAR	highway advisory radio
HAZMAT	hazardous materials
HRI, HRIs	highway-rail intersection(s)
HUD, HUDs	Head-Up Display(s)
IGC	intelligent grade crossing
ISO	International Organization for Standardization
ITE	Institute of Transportation Engineers
ITS	intelligent transportation systems
km/h	kilometers per hour
LACMTA	Los Angeles County Metropolitan Transportation Authority
LED, LEDs	light emitting diode(s)
LRT	light rail transit

LRV, LRVs	light rail vehicle(s)
min	minute(s)
mph	miles per hour
ms	millisecond(s)
MTA	Mass Transit Administration
MTW	multiple train warning (second train warning)
MUTCD	*Manual on Uniform Traffic Control Devices for Streets and Highways*
NCHRP	National Cooperative Highway Research Program
PDA, PDAs	personal digital assistant(s)
PRT	perception-reaction time
SAE	Society of Automotive Engineers
SAIC	Science Applications International Corporation
sec	second(s)
TCD, TCDs	traffic control device(s)
VAB	vehicle arresting barrier