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This study defines the information gathering and communication and response needed for safety at highway-rail crossings. It examines technologies for low-cost, high-safety treatments for low volume highway crossings of higher speed (130–200 kph) rail. Crossing closure and consolidation is a necessary first step. Existing train control and crossing safety systems are examined. Intelligent Transportation System technologies are examined for applicability to the information gathering, communicating, and control functions of grade crossing safety. Guidelines are offered for low volume crossings of the high speed rail line in Oregon. A preliminary cost benefit analysis is presented.

Above 200kph, crossing closure or grade separation is required. In the range of 130–200 kph, ITS technologies have the potential to enhance crossing safety at much lower cost than grade separation. A global positioning system based positive train control system provides the train location and speed information needed for advanced crossing control. A traffic management center can receive train and crossing information, operate crossing systems, and grant clearance for train or highway users through the crossing. Remote lock gates provide safety at private crossings. Increased traveler information and four quadrant warning gates increase motorist compliance at public crossings. At train speeds above 175 kph, barrier gates protect rail movements. Video monitoring and detection systems provide reliable, redundant information should a vehicle become trapped in a crossing.

Low Volume Grade Crossing Treatments for the

Oregon High Speed Rail Corridor

by

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LOW VOLUME GRADE CROSSING TREATMENTS FOR THE OREGON HIGH SPEED RAIL CORRIDOR

1. INTRODUCTION

Highway-rail crossing safety is a fundamental concern for any effort to increase passenger rail speeds in the United States. Since the 1970s $2.3 billion has been marked for crossing improvements in this country. Even so, 1993 estimates from the Federal Railroad Administration (FRA) total 626 fatalities and 1,837 injuries caused by 4,892 collisions at highway-rail crossings (*Texas* 1995). Passive warning systems cannot be relied on, even on low volume roads, when rail speeds increase beyond the original crossing design speeds. Further, as trains reach higher speeds, the likelihood of a collision causing a derailment increases greatly. Highway-rail crossings must be adequate not only to warn motorists, but to fully protect rail travel as well.

1.1 Background

Grade crossings for truly high speed rail operation are technically simple—above 200 kph (125 mph) federal regulations require complete separation of all grade crossings. Below 130 kph (80 mph) the present systems work well or can be upgraded in fairly straightforward ways. The intermediate range of operation, from 130 to 200 kph, presents challenges and possibilities for grade crossing design. Medium and high volumes of highway traffic will still require grade separation wherever possible. Low volume crossings, however, cannot justify the high costs of grade separation. Certainly many, if not most, such crossings will be closed and their traffic consolidated with other, upgraded crossings. But in rural areas, practical alternate routes do not exist for many crossings. New approaches must be found to provide safe, economical low volume crossings.

At the same time, Intelligent Transportation System (ITS) technologies are receiving extensive study and trials throughout the world. Much of this work is directed at improving highway travel. Highway-rail crossings presently are protected by electromechanical systems whose basic operation has not changed in decades. The new communications and control technologies made possible by digital computers and incorporated in the various ITS technologies offer possibilities for greatly increasing highway-rail crossing safety.

1.2 Purpose

Affordable treatments for the many low volume grade crossings are an essential part of any plan for incremental high speed rail development. This research lays the groundwork for developing low cost treatments for low-volume highway-rail grade crossings which will meet the safety requirements of high speed rail corridors. Technologies being developed as part of intelligent transportation systems are evaluated for their applicability to this problem. This background is applied to analyzing the crossings in the Section 1010 high speed rail corridor located in Oregon's Willamette Valley. Treatments appropriate to different classes of crossings are proposed. This report presents the work of the first two phases of a planned three phase project. The third phase will test one or more actual installations at locations identified in the second phase research.

1.3 Scope

This report is based on review of a broad range of literature from government, research, and trade sources relating to grade crossing safety, train control, and intelligent transportation systems. It presents information on current practice and on systems in development in the United States and other countries. It offers a matrix of crossing categories and treatments, design guidelines, and suggestions for further research.

Above 200 kph (125 mph) at-grade crossings are not acceptable. Much of the literature pertaining to high speed rail operations above 200 kph (125 mph) is therefore outside the scope of this report. Pedestrian crossings present special problems; they too are largely outside the scope of this report.

1.4 A Framework for Understanding—Three Tasks

Grade crossing safety depends on the success of three primary tasks: acquiring real-time information about the train; acquiring real-time information about the crossing; and creating correct responses to that information. This typology is closely akin to that of Lerner, Ratte, and Walker; they distinguish between accidents caused by failure to acquire necessary information and those caused by failure to appropriately process and apply information (Lerner et al 1989. pg3-48f). Historically, drivers on the road acquired information by looking and listening at crossings. Train operators looked ahead, visually assessing the condition of the crossing. Correct responses were based on an expectation of good sense—drivers would not try to "beat the train" and operators would apply the brakes if the crossing was not clear. Increasing train speeds, increasing traffic volumes, the need for greater efficiency, and sad experience all have moved us towards more sophisticated systems of control at rail crossings.

Intelligent Transportation System (ITS) technologies hold great promise for improvements in all three of the fundamental tasks required. ITS systems will be essential for providing maximum safety for high speed rail while continuing to improve the overall efficiency and dependability of all rail transportation.

Throughout this report, technologies and techniques, in use and proposed, are discussed as means of acquiring and/or communicating information about train or crossing status or as means of ensuring a correct response to the information provided. We hope that readers will come to look at some technologies in new ways and that new possibilities may emerge for increasing highway-rail crossing safety.

Following this introductory section, the report presents the regulatory framework within which highway-rail crossing treatments must be considered in the United States. The report then presents issues and procedures relating to grade crossing closures and consolidation. Discussion of current, conventional crossing treatments precedes discussion of ITS technologies and their potential application to crossings. The crossings in Oregon are used as a specific set to aid in developing five categories of low volume crossings. These are matched to crossing treatments. The elements of the treatments are described. The report concludes with a preliminary cost/benefit analysis and recommendations for further study. A glossary of acronyms is provided as an appendix.

2. REGULATORY FRAMEWORK

Any consideration of improving highway-rail crossings must take place within the framework of regulations governing both rail and roadway construction and operation. Proposed systems must either fit within existing regulations or be beneficial enough to warrant seeking a change in regulations. Requirements for railroad equipment and operating procedures vary from country to country, as do the speed ranges in which requirements come into effect. Highway design and control also varies significantly from nation to nation. United States regulations provide the primary framework for this report. Our study also is significantly guided by a set of joint recommendations on grade-crossing safety put forward by agencies of the United States Department of Transportation (USDOT). Though not regulatory, these recommendations present a strong direction. Significant departure from this direction would demand justification almost equal to that required for changes to actual regulations.

2.1 FRA Regulations

The Code of Federal Regulations (CFR) 49 Subtitle B Chapter II (parts 200–266) presents FRA regulations. Of particular interest to the development and implementation of high speed rail (HSR) in the United States are regulations which govern requirements for given maximum train speeds, radio communications, grade crossing systems, and the petition process.

2.1.1 Speed Regimes

Throughout most of the United States, standard operating speeds for trains are up to 128 kph (80 mph). Above that speed, several distinct operating regimes have been recognized in federal regulations and recommendations (Table 2.1).

Table 2.1 — High speed rail operating requirements.

Maximum Speed Passenger Service kph (mph)	Requirements
130 (80)	Class 4 Track. Block signals or manual block.
145 (90)	Class 5 Track. Automatic cab signal, train stop, or train control.
175 (110)	Class 6 Track. Automatic cab signal, train stop, or train control.
200 (125)	Requires Special Approval from FRA.
above 200 (125)	Requires Special Approval from FRA. All crossings grade separated.

Standards for maximum speed exist for various classes of track. These are given in CFR 49 §213.9. Track class specifications are given in the following sections of CFR 49 Part 213 and include standards for track geometry, track structure, and inspection schedules. CFR 49 §213.10(c) indicates that operating speeds over 175 kph (110 mph) require prior approval of the FRA. It continues:

> Petitions for approval must be filed in the manner and contain the information required by § 211.11 of this chapter. Each petition must provide sufficient information concerning the performance characteristics of the track, signaling, *grade crossing protection* (italics added), trespasser control where appropriate, and equipment involved and also concerning maintenance and inspection practices and procedures to be followed, to establish that the proposed speed can be sustained in safety.

Maximum speeds are also governed by the type of train control in effect. CFR 49 Part 236 presents standards for signals and train control. Maximum speeds under various controls are given in CFR 49 § 236.0. Other sections detail structural, electrical, and operating characteristics of signals and control systems. Of particular interest for HSR applications is CFR 49 Subpart E "Automatic Train Stop, Train Control and Cab Signal Systems."

Terminology can become confusing at this point. No standard usage has emerged. Harrison (Harrison 1995 pg.117) has suggested that 200 kph (125mph) is the generally accepted minimum threshold to speak of high speed rail. However, federally designated 1010 HSR corridors are generally taking a phase-in approach to high speed rail. Maximum speeds of 150–200 kph (90–125 mph) are typical goals (ibid. pg. 120–121 and see Table 2.2). It is precisely in this range that ITS technologies hold particular promise for allowing at-grade crossings to be maintained with high levels of safety and efficiency, avoiding the costly alternative of full grade separation required for higher speeds.

Table 2.2 — Designated Section 1010 high speed rail corridors.

Corridor	**Length km (mi)**	**Proposed hsr Development**
Washington, D.C. - Richmond - Raleigh - Charlotte	770 (479)	current maximum speed 130 kph; proposed max. 150 kph
Chicago - Detroit	449 (279)	recommended phased program to max running speeds of 200 kph
Chicago - Milwaukee (-Twin Cities)	700 (435)	section 1010 proposal for Chicago–Milwaukee portion is to achieve 150 kph
Tampa - Orlando - Miami	411 (255)	Franchise proposals failed; state still interested in hsr.
Eugene - Portland - Seattle - Vancouver, B.C.	760 (464)	proposed incremental improvements: first phase up to 150 kph, second phase up to max speed of 200 kph

2.1.2 Highway-Rail Crossing Signals

CFR 49 Part 234 governs crossing signal system safety. Of particular note are § 234.223 and § 234.225 which specify timing for warning devices and gate arms. These state that:

- the minimum activation time for any warning system is 20 seconds before the crossing is occupied by rail traffic;
- each gate arm shall start its downward motion not less than three seconds after the lights begin flashing;
- each gate arm shall reach horizontal a minimum of five seconds before any train arrives at the crossing; and
- "At those crossings equipped with four quadrant gates, the timing requirements of this section apply to entrance gates only."

2.1.3 Radio Communications

CFR 49 Part 220 governs radio communications standards and procedures. It prescribes the minimum requirements for the use of voice communications by radio in railroad operations. Transmission of train orders by radio is specifically covered in § 220.61. The use of data radio is not yet included in the CFR, though "digital radio," apparently referring to digital *data* radio from computer to computer, is referred to in Section 11 of the Rail Safety Enforcement and Review Act (*Railroad Communication* 1994).

2.1.4 Petitions for Rulemaking

Operation of any railroad segment above 175 kph (110 mph) requires prior approval from the FRA. Other nonstandard rail system components—crossing warnings, control and communications systems—may also require prior approval or waiver of certain regulations. The requirements for rulemaking petitions and the procedures followed in responding to petitions are presented in CFR 49 Part 211.

2.2 Highway Regulations

In the United States, all highway signs, warning devices, and barriers are governed by the *Manual on Uniform Traffic Control Devices* (*MUTCD*) and the *Roadside Design Guide*. Though these are presented as recommendations only, court rulings have effectively given them the force of required regulations.

2.2.1 MUTCD

Part VIII of the Manual on Uniform Traffic Control Devices contains the standards for traffic control systems at highway-rail at grade crossings. The MUTCD also presents general standards for warning, regulatory, and guide signs, for barricades, and for hazard warning signals as well as other areas which may have application to the design of new systems for safe highway-rail crossings. MUTCD standards are constantly in a process of review and, potentially, revision to incorporate new understandings and give guidance in new situations.

2.2.1.1 Present Standards

Part VIII is titled "Traffic Control Systems for Railroad-Highway Grade Crossings." Section A covers general provisions, stressing the basic themes which govern all aspects of the MUTCD: design, placement, operation, maintenance, and uniformity. Crossings not serving a demonstrable need should be closed. Section B details signs and markings—these are the passive components of warning and control at crossings. Section C covers the active aspects of crossing designs, signals and gates. Where highly variable train speeds are anticipated, constant warning time circuits for signal/gate triggering are encouraged.

The general standards for signs, Part II, will apply to any new signs that may be required for crossing treatments, including variable message signs for traveler information, cf. §2A-5. Barricades and channelizing devices are the subject of section 6.C. In particular, §6C-8 describes the design of type III barricades, which §3F-1 specifies for use at a closure or termination of a roadway—in this case the striping pattern substitutes red and white for orange and white. Section 4E describes hazard beacons as well as signs and devices for other, non-rail intermittent right-of-way interrupting hazards, i.e. movable bridges.

2.2.1.2 New Standards for HSR and Low Volume Roads

MUTCD standards for high speed rail grade crossings are currently under consideration. The National Committee on Uniform Traffic Control Devices discussed several HSR related issues at its January 1995 meeting. Areas discussed include timing sequences for four quadrant gates and absorbing barriers, advance warning signs, constant warning time equipment, vehicle intrusion detection, and crossing-to-train communications. The committee is also concerned that little attention has yet been given to pedestrians at high speed rail crossings (Koester 1995).

Recommended revisions currently under consideration will specify three categories of low volume roads, with varying warning requirements at railroad crossings. Roads with volumes of less than 200 Annual Average Daily Traffic will be considered low volume. Category One is unimproved primitive roads—not graded, not drained, dirt or gravel surfaces. Category Two roads are graded, drained, and have a stabilized surface. Category Three roads are paved. The recommendations suggest railroad crossbucks for all three categories. Railroad crossing advance warning signs would be used for all Category Three roads, but for Category One and Two only where the crossing is not visible an adequate distance in advance. These suggestions assume low volume roads will have passive controls; higher speed rail will require more.

2.2.2 Roadside Design Guide

The *Roadside Design Guide* from AASHTO states:

> "While it is a readily accepted fact that safety can best be served by keeping motorists on the road, the focus of this guide is on safety treatments that minimize the likelihood of serious injuries when a driver does run off the road." (*Roadside* 1989, preface pg. i)

The most fundamental concept for the *Roadside Design Guide* is that of the "clear zone." The clear zone is a variable width region adjoining the traveled way (traffic lane and shoulder) which is to be kept clear of hazards. The clear zone width varies with design speed and topography. The *Guide* calls for hazardous obstacles within the clearzone to be removed or rendered non-hazardous by redesign or protective treatment.

Section 4.6.3 discusses potential roadside hazards from railroad warning devices. Warning device supports for signals or gates can cause an increase in the severity of injuries to vehicle occupants if struck at high speeds. "In these cases, consideration should be given to shielding the support with a crash cushion if the support is located in the clear zone" (*Roadside* 1989, pg. 4-12). The *Guide* cautions designers against protecting the vehicle from the impact of hitting a warning device support in a manner that might redirect the vehicle into the path of a train.

Roadside Barriers are covered in Chapter 5 of the *Guide*. In this context, the roadside barriers considered are those designed for uses alongside a roadway, not across what would be the traveled way. Nonetheless, the basic warrant offered has broader application: "If the consequences of a vehicle striking a fixed object hazard or running off the road are believed to be more serious than hitting a traffic barrier, then the barrier is considered warranted." (*Roadside* 1989 pg.5-2). When considering the possibility of a vehicle causing a train derailment, it may be appropriate to think of this as an extreme case of the "innocent bystander" problem which is considered in section 5.2.3. Such cases typically involve protection of pedestrians or those in school yards or buildings adjacent to busy roads. Barriers may be warranted even if no actual hazard exists in the clear zone.

If impact attenuating barriers are considered for protecting rail traffic with minimum damage to intruding vehicles, Chapter 8 of the *Guide* "Crash Barriers" should be consulted. Movable forms of both energy absorbing drum and dragnet systems have been proposed for rail-highway crossings. Chapter 8 gives considerable information about operational, fixed forms of such systems.

2.3 Rail-Highway Joint Recommendations

As train speeds go up, the need for control of crossings also increases, as does the difficulty and expense of achieving increased control. Table 2.3 shows the three ranges currently designated and the crossing treatments recommended in the *Rail-Highway Crossing Safety Action Plan Support Proposals* which represent the combined thinking of FHWA, FRA, FTA, and NHTSA. Reducing the number of crossings through consolidations and closings is one essential part of creating a safe and efficient high speed rail corridor. For the highest speeds, crossings which cannot be eliminated must be grade separated. ITS applications come into play in the intermediate high speed ranges. In the lower range, from 128 to 176 kph, ITS technologies can help assure driver compliance and safety. In the higher range, from 177 to 200 kph, ITS will assure efficient and reliable protection for the trains.

2.4 Oregon Revised Statutes

ORS 763 presents Oregon statutory law regarding railroad crossings. ORS 763.013 states the policy of the state "to achieve uniform and coordinated regulation of railroad-highway crossings and to eliminate crossings at grade wherever possible;" therefore authority to control and regulate crossings is vested exclusively in the state. Section 763.130 deals with private crossings. Those without automatic warning devices are required to have stop signs, unless placing a stop sign would create a greater hazard. After any required hearings, the state may "alter, relocate, or close any farm or private grade crossing on any line designated as a high speed rail system." For any takings this may involve, the Oregon Department

Table 2.3 — *Action Plan* recommendations.

Rail Speed kph (mph)	Public Crossings	Private Crossings
128-176 (80-110)	Eliminate all redundant or unnecessary crossings. Install most sophisticated traffic control/warning devices compatible with the location, e.g., median barriers, special signing (possibly active advance warning), four quadrant gates. Automated devices should be equipped with constant warning time equipment.	Close, grade separate, and provide a secured barrier or automatic devices for private crossings. Device or barrier should extend across the entire highway on both sides of the track, should normally be closed and opened on request, if no train is approaching, for a period of time sufficient to cross the track(s).
177-200 (111-125)	Protect rail movement with full width barriers capable of absorbing impact of highway vehicle. Include a fail safe vehicle detection capability between barriers. Notify approaching trains of warning device or barrier failure or of an intruding vehicle in sufficient time for the train to stop short of the crossing with out resorting to emergency brake application.	Protect rail movement with full width barrier or gate, normally closed and locked, capable of absorbing impact of a highway vehicle. Gate lock or control should be interlocked with train signal and control system and released by a railroad dispatcher. A fail safe vehicle detection or video system should monitor the area between the barriers. The crossing should be equipped with a direct link telephone to the railroad dispatcher.
above 200 (125)	Close or grade separate all highway-rail crossings.	Close or grade separate all highway-rail crossings.

of Transportation may use its power of eminent domain. Payments may be made from designated HSR funds.

3. RECOMMENDED FIRST OPTION—CROSSING CONSOLIDATION

The most direct safety improvements come from eliminating at-grade highway-railroad crossings. The *Rail-Highway Crossing Safety Action Plan Support Proposals* recommends consolidation/closure or grade separation for all crossings where trains will operate above 200 kph and wherever possible where trains operate between 128 and 200 kph. Consolidation of crossings allows a greater concentration of resources for upgrading remaining crossings. The goal is to balance the inconvenience caused by closures with increased access over nearby crossings. Ideally, enough resources would be available to grade-separate remaining crossings. Where this is not possible, ITS technologies can offer economical possibilities for providing a significantly improved level of safety and convenience at remaining crossings. In addition, some very low volume crossings, principally private, often agricultural, crossings, cannot practically be served by other consolidated crossings. In these instances it is particularly necessary to provide low-cost, safe alternatives to grade separation. Consolidation allows wise use of resources where they are most needed for the particular circumstances of each rail corridor.

3.1 Recommended Procedure

Crossing elimination is typically part of a larger process of crossing consolidation along a rail corridor. This may be as part of a safety improvement plan. It may be in response to local officials' requests for crossing upgrades. Where crossings are largely redundant, some may be closed while those retained are upgraded.

In any crossing elimination, local approval is vital. Even if the state has the authority to close a crossing, it very rarely will without local agreement. In the *Guide to Crossing Consolidation and Closure* (*Highway-Railroad* 1994) FHWA and FRA recommend a process to reach safe, well supported decisions about closures.

The process begins with screening the crossing proposed for closure. The planner or engineer checks the particular crossing and those surrounding it for safety and the level of redundancy. Approval to close a crossing is very rarely based on safety issues. The most successful projects have an alternative route which will not significantly increase travel time (i.e. the crossing is redundant). It is difficult to close a hazardous crossing that is not redundant. Traffic safety is nonetheless of great importance. It is vital, if consolidation is going to be achieved, that the diverted traffic goes across the track at a point with a greater level of warning devices and that the crossing can also accommodate the increased level of traffic. The process continues with coordination of state and local authorities, community profile and participation, and a working-through of corridor analysis. This crossing consolidation process can be time consuming. It is important, though, that the guidelines be followed if the consolidation is to succeed. If two or more elements of the model are missing then, more often than not, the consolidation will fail. The *Guide to Crossing Consolidation and Closure* provides a grade crossing consolidation check-list.

3.2 ITS and Consolidation

Crossing consolidations can often make funds go much further in upgrading remaining crossings. Nonetheless, full grade separation for the remaining crossings would be very expensive and even the first step—consolidation and closure of crossings—may prove very difficult in practice. ITS technologies may offer safe, reliable, efficient, and affordable alternatives for areas where trains will operate up to 200 kph. The *Action Plan* proposals for high speed rail crossings call for sophisticated traffic control/warning devices in both of the intermediate speed ranges above 128 kph. These devices all must function together in systems which meet the three fundamental tasks of crossing safety.

3.3 Demand Management—Trading Property

Opportunities should also be sought to reduce the need for crossings. Many private crossings serve agricultural lands. Often the rail line cuts through farm land with comparable qualities on either side. In situations where farmers living on opposite sides of the line each have farm lands on the other side, it may be possible to arrange land trades to consolidate each farmer's property, each on one side of the tracks and accessible without crossings. Such a plan would not be simple. Acreage and land quality would seldom be quite equal; often a farmer's land is leased, not owned by the farmer. Even with the difficulties, avoiding the expense and risk of grade crossings may make it worth the effort. Where circumstances look promising, financial incentives for cooperation may be justified. The costs may even justify an extension of eminent domain to force such consolidations.

4. CONVENTIONAL HIGHWAY-RAIL CROSSING PRACTICE

Crossing conflicts, by definition, can occur only when a train enters or occupies an at-grade crossing. Given the presence of a train, the other half of a grade crossing conflict is the presence of another vehicle or pedestrian in the crossing. Preventing conflicts without eliminating the at-grade crossing requires knowledge of both the trains approaching the crossing and of the crossing itself—whether vehicles are present and if the crossing control equipment is functional.

Needed knowledge of train status includes the trains' location, direction of travel, speed, and stopping distance. Traditional timetable/train order and manual block signal systems provide guidance to train operators and knowledge of where trains are supposed to be. Automatic block systems, including those that incorporate automatic controls, rely on track circuits to detect the presence of a train in a given section of track and in the case of control systems, to relay information about train speed.

Knowing the status of the crossing means knowing whether conflicting traffic is blocking the crossing. It also means knowing how dependable the crossing information is. As with trains, traditional methods have relied on warnings that make clear what the crossing status is supposed to be. When the lights are flashing and the gates down, no other vehicles should be entering the crossing. But this is not necessarily the actual reality. The problem of acquiring information about train and crossing status can further be understood from two separate angles: from the railroad side, train operators/systems must recognize the approach of the train to a potential conflict spot and determine if a conflict exists; from the highway side, drivers need to know of a deadly hazard—the train—interrupting or about to interrupt the roadway.

4.1 Highway Approach

Motorist error is the primary cause of train-motor vehicle accidents (Rozek 1988, pg.49). The motorist must first be aware that a crossing is ahead. Then it is necessary to evaluate whether or not the crossing can be safely negotiated or whether it is necessary to stop for a present or oncoming train. Both vision and hearing are relied on to convey the required information. In passive systems, the driver must further use judgment to estimate the approach of a train in relation to his or her time to complete crossing the tracks. In active systems, the presumption is that judgment is not required—when the gate is down it is not safe (as well as not legal) to proceed. Experience indicates that many motorists do not follow this presumption.

4.1.1 Passive Warning Systems

A passive warning device, typically the standard railroad crossbuck, alerts motorists to the presence of a highway-rail crossing. After being alerted to the upcoming crossing, awareness of an approaching train is based on motorists' vision and hearing. Sight distance is critical to reasonably safe functioning of crossings protected only by passive warnings. Sight is augmented by the "active" function of the train whistle or horn sounded by the train crew as they approach the crossing. Passive warnings are not adequate for HSR lines.

4.1.2 Active Warning Systems

Active warning systems include flashing lights, bells, and warning gates. Current standard active warning devices for grade crossings are based on track-circuit activation. At a fixed distance from the crossing, the presence of a train will activate the warning lights, bells, and if present, gates. Constant warning time systems use more sophisticated track circuits for more sophisticated control.

4.1.2.1 Standard Fixed Activation Point

In older systems where the location of the activation point is fixed, it must be related to the maximum authorized speed (MAS) for that part of the line. In no case may less than 20 seconds warning be given before a train enters the intersection. Where gates are present, those controlling approach traffic must be completely deployed (horizontal) not less than five seconds before a train enters the crossing.

4.1.2.2 Constant Warning Time

At most crossings in the United States, the crossing activation circuit cannot recognize varying train speed and so the crossing warning time may vary greatly from train to train. Systems which do recognize train speed and provide a relatively constant warning time (CWT) are installed at about 6,000 crossings in the United States. The technology for current CWT was developed in the 1960s and uses a more complex, discriminating set of track circuits (Bowman et al. 1986). They have been found to be effective in reducing warning device violations by motorists (Halkias & Eck 1985, Bowman 1987).

4.2 Railroad Approach

Train crews must be aware of their approach to a crossing. They must be able to assess the status of the crossing—is it clear? can they proceed? Finally, they must be able to respond to a blocked or defective crossing in a way consistent with the train control standards under which they are operating.

4.2.1 Crossing Status

Train crews must assess the status of a crossing visually as they approach. They must first be vigilant enough to know they are approaching a crossing. They then require adequate sight distance—a clear view of the crossing from a great enough distance that a full service brake (FSB) would stop the train before it entered the crossing. Poor weather—fog, snow, or heavy rain—may limit vision. At night, pedestrians, bicyclists, and perhaps stopped cars may not present the side lighting needed to be seen from up the track. Even when the crossing and its approaches can be clearly seen, the train operator's response must be based on judgment of whether approaching vehicles will indeed stop, and the assumption that stopped vehicles will remain stopped until the train is past.

4.2.2 Train Control

Traditionally, train operators have been aware of their position relative to crossings by knowledge of the line and by vision. Traditional railroad signal and control systems have been designed to locate trains in relation to other trains and track control features (e.g. switches). *These systems have not generally been tied to highway-railroad crossings.* Nonetheless, a basic understanding of block systems will help in understanding how more advanced train control systems can be integrated with crossing control.

To prevent two trains from trying to occupy the same piece of track at the same time—a highly undesirable circumstance—tracks are sectioned into blocks and trains must have an authority to occupy any given block. Authorities have been conferred by timetables and train orders, but a simple statement of what train should be where and when cannot deal with delays, breakdowns, or other unforeseen circumstances.

An example may help clarify the central idea of track authority. One early system vested authority for a block in a single token. The train engineer would pick up the token at the start of the block and carry it to the other end. Only a train carrying that token could enter that block. Obviously this only worked where trains always arrived from alternating directions.

4.2.2.1 *Automatic Block Signals*

Today, most passenger rail lines are equipped with automatic block signals (ABS) (Ulman and Bing 1995). Any train present in a block, along with the switches and the rails themselves, creates an electrical circuit which controls the signals related to that block. If a train occupies a block, signals at the entrance to that block will be set to stop. Signals in the preceding block(s) will be set to caution. Other blocks will show a clear signal. The various block signals are called "aspects." In a simple three-aspect ABS system, a train operator seeing a caution aspect must begin to stop and the block length must be sufficient to permit a safe stop from the maximum authorized speed (MAS). ABS systems with more aspects provide levels of caution, effectively lowering the MAS for a block under an early caution aspect. This then allows shorter block lengths, more sophisticated train control, and closer headways.

4.2.2.2 *Central Train Control*

ABS, as described above, applies to track with an established direction of travel, as one would have with double tracks each signaled for travel in one direction. Bi-directional use of single track requires a more complex traffic control system (TCS). Where all interlockings and control points are controlled from one location, this is called centralized traffic control (CTC). Control is typically through coded track circuits—several distinct codes can be sent at one or more carrier frequencies through the track in a block. Areas without CTC are "dark" regions. CTC areas are visible to dispatchers at a resolution fixed by the block length. The dispatcher knows whether or not a train is in a given block. Without calling the train operator, the dispatcher can only infer which train is in a block and what its speed and direction are. Even in a system with several signal aspects, each block must be long enough for significant change (higher speed to lower, lower speed to stop). This greatly limits the precision of the dispatcher's knowledge.

4.2.2.3 *Cab Signals*

At higher speeds it becomes more difficult to accurately read wayside signal aspects from the engine cab. Above 130 kph (80 mph) train operations must be protected by some means of compensating for this difficulty. Cab signals bring the aspect indications for the block into the cab with the train operator. In addition to continuously indicating the current aspect, a change to a more restrictive aspect is accompanied by an audible signal which continues until manually acknowledged.

4.2.2.4 *Automatic Train Stop*

Another approach to protecting higher speed operations is a system which will automatically apply the brakes if the operator fails to respond to a more restrictive condition coming into effect. As with cab signals, automatic train stop is tied to the automatic block system or central train control. Also as with cab signals, an audible warning sounds in the cab when a more restrictive condition is encountered. The train operator must respond to the restriction or the ATS will apply the brakes.

5. ITS TECHNOLOGIES

5.1 Introduction

ITS technologies hold promise for improving information, communication, and control at highway-rail crossings. These may be combined to provide levels of safety unattainable with conventional approaches at a cost still far below that of full grade separation. Various component systems, linked by digital communication channels, can greatly enhance the ability of train operators and motorists to succeed at the three tasks of crossing safety.

In the United States, it has been the responsibility of drivers to correctly recognize and respond to approaching trains. Passive signs combined with the sight and sound of approaching trains or the use of active warning devices are expected to create an appropriate response. On low volume roads and with trains operating in the range of 128 to 176 kph warning devices alone may still be adequate crossing protection. For this to be the case, the warnings must be convincing. Along with basic education and enforcement, ITS can help provide consistent, reliable, and convincing information to assure the highest level of compliance.

ITS technologies offer options for far more powerful tracking and communication of the status of trains throughout a rail network. Using digital computing and signal technologies to acquire and transmit such knowledge lends itself to connection with other information and control systems required for safe grade crossing operation.

Direct vision has been the train operator's only tool for checking the status of each crossing as the train approaches. ITS technologies provide monitoring of the true conditions at crossings. Technologies as familiar as loop detectors and as new and rapidly developing as video detection and Doppler radar are being used or show promise for monitoring crossing status. Again, computer analysis, communications, and control possibilities allow this acquisition of crossing status to fit into a complete system of safe crossing operation.

In principal, the correct responses to a potential conflict are quite straightforward. If a train is approaching, vehicles in the crossing must clear it and no other vehicles enter. If this fails to happen, the train must stop before entering the crossing. A slightly more subtle but equally important issue is the handling of failed equipment and systems. If the condition of either the train or crossing equipment is compromised, a set of actions must be initiated to assure continued safety at the crossing through the completion of repairs.

What is simple in principal is more difficult and/or expensive when the stakes are high and those responsible are ordinary human beings. In any grade crossing accident, the likelihood of death for those in a car or truck is very great. When considering high speed passenger rail, the possibility of a collision leading to derailment and disaster is very real. Acceptable operation of high speed rail requires complete compliance with safe practice by both train crews and motor vehicle drivers at all crossings. Timely and accurate information can improve the consistency and appropriateness of human responses. Dependably accurate information is also critical to acceptance of positive controls which prevent human errors, e.g. automatic brake control for trains and fully closing crossing gates for road vehicles. Consistent enforcement of regulations also can create an expectation of compliance and apparently a stronger disincentive to violation than the thought of merely killing oneself and hundreds of others. ITS technologies combined with both traditional and newer crossing barrier designs can create effective controls to assure safe responses to potential conflicts at road-rail crossings.

5.2 Train Control

The traditional approaches to knowing train status cannot provide precise information about location and speed, but have still worked very well at providing safe and reasonably efficient train control and crossing warnings. However, as train speeds are increased, and so also the range of speeds from train to train, more detailed information is needed for operations that will be safe, efficient, and acceptable to the public. In the United States and in other countries, new train control and railroad management systems have been proposed and/or are being used. In some instances these are directly tied to grade crossings. In others, the technologies have been developed for train control, but can be extended to incorporate crossings into the train control system.

5.2.1 Moving Blocks

A more constant and detailed knowledge of train location and speed is highly desirable for many aspects of railroad management and can provide opportunities for optimized control of grade crossings. With the ability to exchange detailed information afforded by digital technologies, the concept of a "moving block" becomes central. Rather than a fixed section of track, blocks are thought of as buffer zones that exist before and behind a train. The block moves with the train. For this to work, control systems must know the location and movement of the train. The relatively simple wayside-only systems used for ABS are replaced by on-board computers in two-way communication with wayside and/or central computers. Moving blocks provide the closest possible safe headways. Systems to implement this concept exist and are seeing wider use throughout Europe and the United States.

5.2.2 ATCS/ARES/PTC

In the United States and Canada, standards have been adopted for advanced train control systems (ATCS). The full standard offers excellent opportunities to apply advanced technologies to the problem of grade crossing safety. But the railroads have adopted a piecemeal approach to implementation, as costs could be justified. A scaled down form of the most safety critical systems, positive train control (PTC), is also only finding a home on the most congested corridors. Though newer technologies are in some cases overrunning ATCS before it is even tried, study of how ATCS subsystems could connect with grade crossing equipment provides a useful model for further development of the newer technologies.

5.2.2.1 ATCS/ARES

The ATCS standards have been developed jointly by the Association of American Railroads (AAR) and the Railway Association of Canada (RAC). ATCS uses mobile data radio to convey information. As originally conceived, ATCS uses wayside transponders to reset the train odometer. A closely related project conducted by Burlington Northern—Advanced Railroad Electronics System (ARES)—used a global positioning system (GPS) to constantly track and report train location.

ATCS is grounded on the principles of open, nonproprietary system architecture and system-wide interoperability. The system is intended to remain open to technical innovation and to allow engines from any railroad to operate in full compliance with the system on any other railroad. The communications network adopts the International Standards Organization's Open Systems Interconnect model (Bartoskewitz and Richards 1995, pg.3). ATCS calls for communications to use the six channels in the 900 MHz (UHF) band allocated in the United States and Canada for railroad communication. The ARES project used VHF frequencies. VHF allows for greater distances between base stations. UHF may be less affected by RF interference in congested areas (*Railroad Communications* 1994, pg.44). Wayside-to-cab and cab-to-wayside digital communications link trains to dispatch, track control devices (e.g. switches), and maintenance-of-way forces.

Many subsystems comprise the full ATCS. Those most directly related to safety are often spoken of under the titles Positive Train Separation (PTS) or Positive Train Control (PTC). Other components of the ATCS standard also have important, though less direct, safety implications, e.g. work order reporting and real-time communication of track warrants to maintenance-of-way forces.

ATCS has five major elements: the central dispatch computer, the locomotive on-board computer, the track forces terminal, the wayside interface unit, and the communications system which connects all of these. Mobile data radio is the carrier for most of the information exchange which comprises the system, though wayside units may also connect to the dispatch computer by telephone lines or fiber optic links (Poltorak 1991). The communications and control standards of ATCS lend themselves to more sophisticated grade crossing systems.

Within the ATCS, the work vehicle system may provide a starting point for a request-based opening of a crossing. The system consists of three components: the mobile communications package, the track forces terminal, and a display. Though it is used for a variety of communications and control needs for track work gangs, of primary interest here is the ability of the system to request, secure, and release track occupancy authority (Poltorak 1991). A similar system could be used at crossings to control authority to open a gate and cross the track. Authorities are granted by the central dispatch computer only if they can be safely accommodated. This can be done without any requirement for human response, though human intervention is always possible. Once the authority is in place, all of the automatic safeguards of the system are in force to assure that no approaching train will enter the occupied track—in this case the crossing occupied by the vehicle on the road. This corresponds to the German approach to private crossings—a presumption that an open gate means an occupied crossing.

ATCS field devices also provide useful models for components of a road-rail crossing. Controllable devices include those which interrupt a route. Noncontrollable devices include intrusion detectors and various integrity indicators (Poltorak 1991). The opening of a crossing can be thought of as an interruption to a route—a train cannot be permitted to enter an open crossing anymore than it can be permitted to reach a wrongly set switch. Intrusion detectors would include any of the possible ways of detecting the presence of vehicles in a crossing, e.g. loops or automatic video interpretation. Integrity indicators can be monitored to determine the good working order of the crossing systems and automatically impose appropriate safety restrictions on approaching trains as well as initiating notification of repair and safety crews. Within the ATCS protocols, all field devices along a route must confirm safe conditions before track authority is granted for a train.

5.2.2.2 PTS/PTC

Positive train separation is the narrower of these two terms. It refers, essentially, to a train-train collision avoidance capability. Positive train control is broader and includes the ability to enforce speed restrictions, both permanent and temporary. The ATCS approach to PTC would provide constant monitoring of train position, estimated braking distance, speed restrictions, and track warrants. Minimum headways and maximum overall speeds are achieved through moving block signaling. A more conventional approach to PTC is being implemented in the Northeast Corridor (NEC).

5.2.2.3 PTC ON THE NORTHEAST CORRIDOR

Under a conventional TCS, Automatic Train Control (ATC) and Automatic Train Stop (ATS) carry out some of the functions of PTC without the moving block capabilities. Currently, 10,000 km (6,212 mi.) of United States railroad is equipped with ATS or ATC. (*Railroad Communications* 1994, pg.37). In intermittent systems, the ATS/ATC responds to signal beacons at critical control points. Continuous systems interface with the track circuits. On the north end of the NEC—Boston to New Haven—Amtrak is upgrading the line from the current four aspect signal system to a nine aspect system. This is being done through extension of the existing coded track circuits. The single frequency, 3-code system is being upgraded to a two frequency, 8-code system. Automatic cab signals are used. The additional aspects and other upgrades will allow increased overall speeds, enforcement of civil engineering speed restrictions, and positive train stop at key control points. The train stop capability is an intermittent system. The system is designed for speeds up to 240 kph (150 mph) (*Railroad Communications* 1994, pg.47f).

5.2.2.4 *The Future of ATCS/PTC*

ATCS/PTC could provide critical knowledge and opportunity for advanced crossing control. Train location and speed are accurately known. Communication and control links among trains, dispatch, and all devices along the route could include crossing treatment components. Unfortunately, the future of ATCS is far from clear. Key advantages, for instance the detailed information needed for moving block signaling, are seen as expensive and difficult to justify outside of congested areas. Newer technologies are being applied to specific problems met by various ATCS components, e.g. cellular phone data communication for work order reporting. Of particular interest is the continuing research into GPS based PTC systems and their application to grade crossings. The Union Pacific Railroad is currently working toward a test installation of a GPS/PTC activated grade crossing system. They are particularly interested in the potential to provide sophisticated control without expensive extensions to track control circuit systems. AAR is showing flexibility in looking at alternate data paths, e.g. VHF, cellular. Consideration of how best to assure highway-rail crossing safety must look at the full spectrum of options available and cannot assume ATCS technologies on HSR corridors.

5.2.3 Train-Type Transponder—Sweden

One of the simplest, yet most useful pieces of information needed is the ability to distinguish between slower freight and higher speed passenger trains. The Swedish State Railway uses an activation beacon which recognizes the distinct signal from a high speed trainset onboard transponder and activates the crossing warnings and gates early enough to clear the crossing. When a slower freight passes the beacon, the crossing gate activation is delayed appropriately to minimize disruption of normal traffic. The Swedish system also follows the activation beacon with a check beacon located at the minimum distance required for a full service brake to stop a high speed train before the crossing (High Speed 1994). It is interesting to note that the Connecticut Department of Transportation's proposal for a crossing following Swedish principles apparently does not include distinguishing train speeds. They feel four-quadrant gates will be sufficient to ensure compliance even from anxious motorists dealing with advance warning times of up to 150 seconds (Leete, R. 1994).

5.2.4 CATC—Germany

The German Railway (Deutsche Bahn, DB) developed its high speed rail signaling system initially for trains running up to 190 kph (120 mph) on existing lines. It is now used for Intercity-Express (ICE) trains in Germany and other European countries running up to 280 kph (175 mph). The system combines continuous automatic train control (CATC) along with associated on-board automatic speed control (ASC), decentralized microcomputer interlockings for safeguarding routes, and operation control center automatic train supervision. Signaling is through an inductive loop laid between the tracks. The CATC accounts for schedule, train speed and braking curves, and terrain while always maintaining train protection. Redundant computers in a 2 of 2 or 2 of 3 agreement protocol are used throughout the system. Trains can travel at nearly the shortest possible moving block headways.

On sections of the DB equipped for high speed operation, data are transmitted between the train and wayside and central controllers by means of an induction loop located within the gage of the track. The induction loop is built with crossovers at fixed distances. These are detected by the train passing over and used to reset the on-board odometer. The odometer and speedometer are constantly polled by the on-board computer and the information also relayed via the induction loop to the other elements of the CATC system (Hümmer 1991). This induction loop/crossover system is also used by Vancouver, B.C.'s Skytrain rapid transit system.

5.3 Vehicle Location and Data Mapping

5.3.1 Geographic Information Systems

A Geographic Information System (GIS) has been developed to better follow and understand rail-highway crossing safety data (Faghri 1995). This system is intended for analysis of data collected over a period of time. GIS are also finding application in real-time situations in the dispatch of emergency vehicles. A GIS lends itself to integrating data relevant to grade crossing management in a dynamic and powerful tool. Train location on the line can be shown, with colors coding for important information such as speed, class of train, and current block authority. Intrusion detection devices can give a running count of traffic volume on the cross street as well as flashing a blocked crossing condition. Over time significant data can be gathered about driver behavior at particular crossings. Having all of this gathered in one GIS may provide unprecedented power for understanding and managing crossings. Real-time vehicle location data, from GPS or other automatic vehicle location systems (AVL) along with traffic data from loop detectors and/or video image processing/detection systems are increasingly being pulled together as layers on top of GIS maps showing streets, rail lines, construction, and utilities. Incorporating train status, especially at and near highway-rail crossings, could provide a valuable tool for coordination and optimizing responses of emergency vehicles.

5.3.2 Automatic Vehicle Location

Automatic vehicle location systems are seeing increased use for transit and emergency vehicles. The systems are parallel to those discussed for train control systems. Seeking common standards may hold promise for crossing safety, especially for the safety of critical trips—buses, hazardous materials, and emergency vehicles.

In some instances, transponders on vehicles are recognized by roadside or in-the-roadbed beacons/detectors. These roadside stations report the vehicle location to a central control station, often feeding directly into a GIS representation of the area. The beacons may also report their, fixed, location to an on-board computer as an aid for traveler navigation or schedule compliance. This parallels the ATCS train location standard.

In other systems, vehicles locate themselves by means of a Global Positioning System (GPS). Analysis of signals received from several satellites allows on board calculation of vehicle location. Again, the information can be used for vehicle navigation systems. Digital data radio can be used to exchange vehicle location information with a central control center as needed. This parallels the use of GPS in the ARES project.

5.4 Traveler Information and Warning

5.4.1 Automatic Whistles

Various options have been explored or can be contemplated for improving motorists' ability to recognize the approach of a train to a crossing. On the simplest end, the John A. Volpe National Transportation Systems Center (VNTSC) is doing FRA sponsored research on audible warning devices installed directly at crossings as a substitute for traditional train whistles. Some field testing of an Automated Horn System (AHS) mounted at a crossing has been done at the City of Gering, Nebraska (*Rail-Highway* 1994, pg 15).

5.4.2 Vehicle Proximity Alerting System

It has been suggested that the Vehicle Proximity Alerting System (VPAS) being developed by FHWA has the potential to interface with ATCS (*Railroad Communications* 1994, pg.vii). Such a system is particularly intended for vehicles carrying critical loads. This has appeal in light of research indicating that requiring buses and hazardous material transporters to stop at crossings with active warnings when the warnings are not activated significantly increases accidents with trains (Bowman et al. 1986). The VPAS could be seen as an acceptable alternative to the heightened visual and auditory checking which is supposed to occur when critical load vehicles stop at all crossings.

5.4.3 Constant Warning Time

Constant warning time (CWT) track circuits were developed in the sixties and are installed at over 6,000 crossings in the United States (Bowman et al. 1986). They have been found to be effective in reducing warning device violations by motorists (Halkias & Eck 1985, Bowman 1987). It is not clear what factor is most important—the elimination of long waits for slow trains, or the consistency of warning which increases motorist trust in the warning.

A GPS based PTC system could provide the needed information to eliminate long waits and/or provide motorists with trustworthy information about approaching trains, e.g. through variable message signs. ITS highway monitoring technologies could provide another low-cost alternative to conventional track circuit or to ATCS-based knowledge of train location and speed for the activation of crossing warnings and protective barriers. Video and Doppler radar based vehicle detection systems could be turned up the tracks to detect and report train progress toward a crossing. These will be discussed at greater length in later sections.

5.4.4 Traveler Information Systems

Traveler Information Systems (TIS) are being developed and tested as means of aiding navigation and giving real-time information, as for example directing traffic away from congested streets. The information may come to the motorist through on-board data terminals or graphical displays. It may be presented from fixed locations through variable message signs or through local travel information radio signals.

5.4.4.1 *ON-BOARD*

Real-time, in-vehicle traveler information systems being developed as part of ITS could pick-up information about on-coming trains and provide a warning. As an example of how such a system might work, consider the Comprehensive Automobile Control System (CACS) research sponsored by Japan's Ministry of International Trade and Industry. In this system, vehicles send an ID and a destination code to a loop at each intersection. The intersection returns turning directions based on route, but also on real-time traffic information (Yumoto 1995, pg.111). Such a location keyed system could be expanded in a straightforward way to check if a route crosses a rail line and if a train is coming it could provide additional warning or alternate routing to a grade separated crossing. The vehicle IDs could also be used to warn train crews of critical vehicle types approaching the crossing.

Taking this one step further, the GIS/GPS in-vehicle navigation/travel optimization systems now being developed could initiate exchange of data about train status from railroad systems. Through mobile data terminals, drivers—or the computer system directly—could query the train control system about how long a given crossing will be open before the next train approach. Emergency vehicles could have codes to send out a pre-emption signal to a given crossing and receive back confirmation that an approaching train is braking to allow the emergency vehicle to pass through the necessary crossing without danger of collision.

5.4.4.2 *ROADSIDE*

Excessive delay can lead anxious motorists to non-compliance with highway-rail crossing warning devices. Rozek and Harrison state that motorists find any delay greater than 50 seconds "annoying and troublesome" (Rozek and Harrison

1988, pg.51). Leete suggests the industry standard has been belief that "warning times in excess of 40 seconds would encourage an anxious motorist to drive around a downed gate" (Leete, 1994). It is our belief that driver uncertainty is a primary factor in increased non-compliance with longer delays. With ITS technologies it is possible to give waiting motorists real-time updates on how long they will have to wait. A variable message sign can be tied into the system to count down the remaining time until the expected arrival of the train. If a full ATCS is implemented, information about train length would also be present in the system and the message could indicate the amount of time left until the crossing will open again. Figure 5.1 shows a sample of a repeating, updating sequence of messages on a variable message sign. A separate fixed sign could direct drivers to the nearest grade-separated crossings in either direction along the track. In the event of a trapped vehicle, the variable message sign could be used to assure and caution other motorists (Figure 5.2). In addition to visual information through a variable message sign, the same information could be provided audibly through a leaky coaxial cable broadcast along the approaches to the crossing. A permanent sign would direct motorists to tune to the proper frequency for train information.

5.5 Incident Detection

Incident detection systems may simply note the presence or absence of a vehicle in the area they cover. They may be designed to sound alerts based on stopped vehicles. They may track a wide range of sophisticated traffic properties, noting not only stopped, but also slowed vehicles, as well as speed, distance, and headways of approaching vehicles. Systems may be automatic, human monitored, or automatic with information based on inferences from other systems. Incident detection has focused on detecting motor vehicles, but monitoring train status approaching crossings may also be an appropriate use of these technologies.

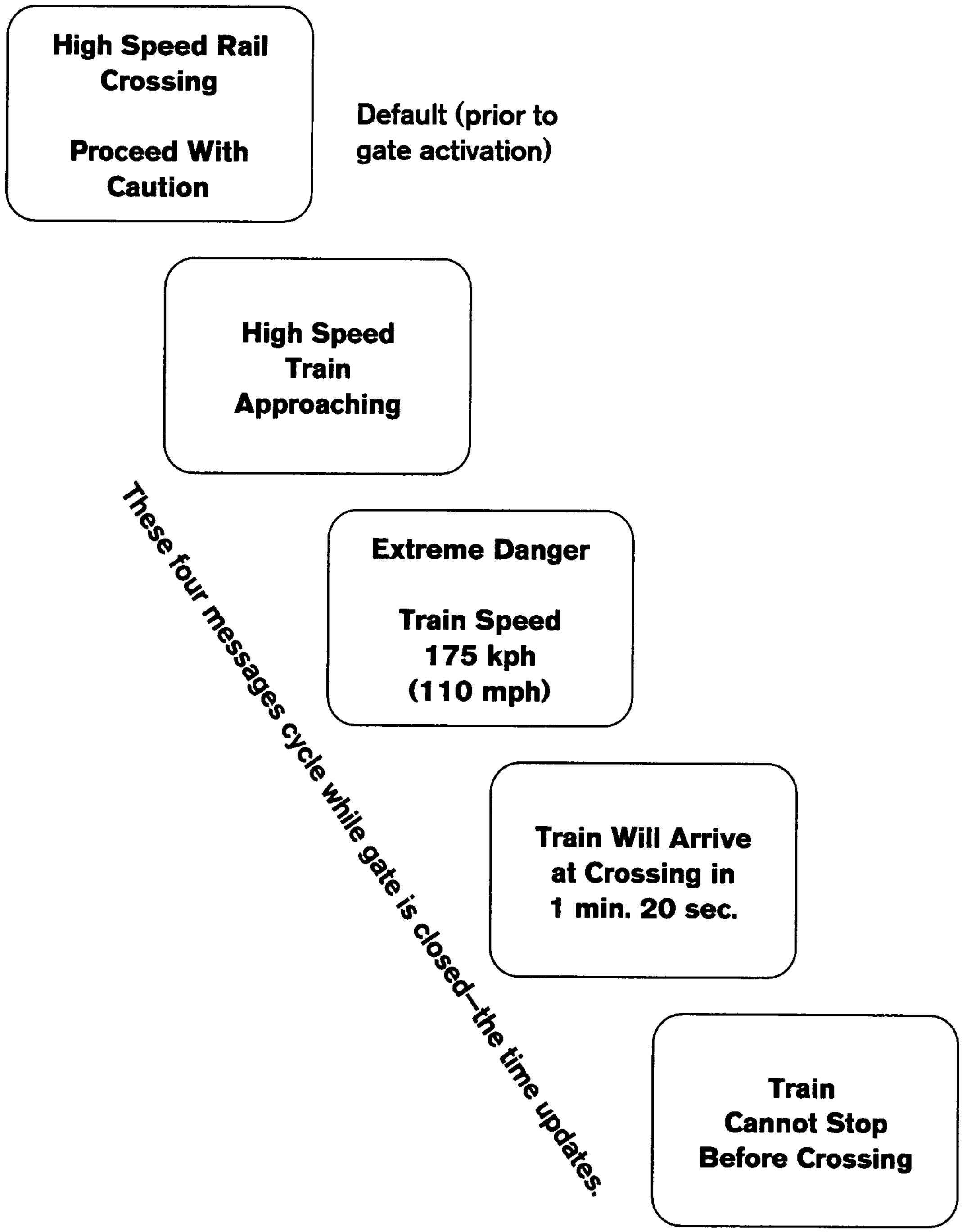

Figure 5.1 — Repeating, updating sequence on variable message sign.

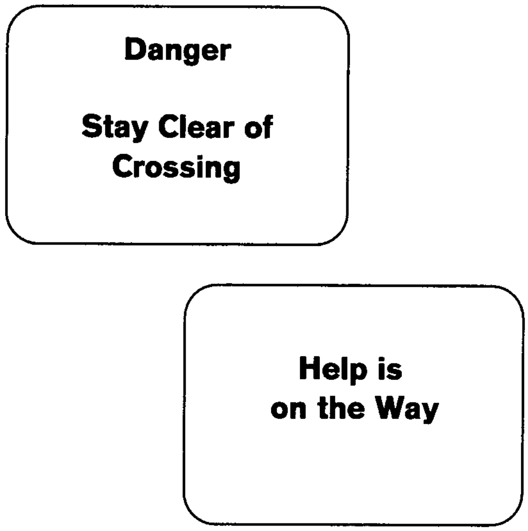

Figure 5.2 — VMS use as part of trapped vehicle response.

5.5.1 Monitored Gates

On the German Federal Railway, rail crossings are regulated by the Eisenbahn Bau- und Betriebsordnung (EBO). Low volume, private crossing status is controlled by gates tied into the block signaling system. An open gate is presumed to indicate an occupied crossing and a closed gate to indicate that the crossing is clear (Bauer 1995, *EBO* 1992). The *Action Plan* recommends such a linking of normally closed gates into the signal system for private crossings of lines operating from 177 to 200 kph, though it also calls for separate intrusion detection as a fail safe.

5.5.2 Crossing Telephones

Telephones located at crossings provide direct communication with train dispatchers controlling the rail line. In the United Kingdom, there are 4,500 private crossings in England. Of these, 1200 are controlled with telephones. At these private crossings, the motorist telephones the control signalman before and after crossing. The control signaler sets a restrictive aspect on the block with the crossing, then clears it after the second call. If the second call is forgotten, the train must proceed with caution and report the crossing status to the signaler. Some blocks in England are 32 km (20 mi) long—a crossing in use anywhere in this length restricts the use of the whole block (Hunter-Zaworski 1995).

In this country, the enormous growth in cellular phone use may warrant placing of permanent signs at crossing indicating a number that can be dialed for operations in connection with the crossing. An extension given with the number could automatically identify the crossing to the human or computer monitor receiving the call. Whether by cellular or conventional lines, calls might be used as in Britain, for crossing clearance. Telephones also could be used to report problems, or to retrieve train status or alternate route information.

5.5.3 VIDEO MONITORING

Direct, human monitoring of crossing status by video can provide a redundant level of safety and a check on the correct functioning of automatic systems. Video monitoring can be by train operators in-cab as they approach a crossing, or in the central dispatch office, or in a separate location—created specifically to monitor crossing safety or as part of a larger transportation management center.

5.5.3.1 VIDEO MONITORING AND MANUAL CROSSING CONTROL

In the United Kingdom, semi-manual operation of crossings is more common than fully automatic systems. Closed Circuit Television (CCTV) shows the signaler each crossing as needed. The screen for a given crossing remains blank until a train approaches. The train signal is restrictive until the signaler has manually lowered the barrier (our standard gate type) or swung the gate (older style gate that swings across tracks to open roadway). Half barriers or staggered operation of four quadrant gates allow motorist escape. Once the signaler has determined that the crossing is clear, he or she changes the signal and the train can proceed at speeds up to 200 kph (125 mph). When the train passes the crossing, the gates open automatically.

5.5.3.2 IN-CAB VIDEO

In-cab video monitoring of grade crossings has been demonstrated by Wireless Technologies, Inc. in cooperation with the New York State DOT at the Lincoln Avenue crossing on Conrail's Chicago Line, Albany Division. Wireless Technologies is a Los Angeles based manufacturer of radio frequency (RF) video transmission systems. They installed Autoscope video detection equipment and a radio transmitter directed up the line. Beginning slightly over four miles up the track, the on-board receiver they installed picked up the signal and displayed live video of the crossing in the cab of the train as it approached at speeds up to 160 kph (100 mph). Figure 5.3 shows a typical sensor coverage for the system. The display also included a rectangular area superimposed over the crossing image which changed color to indicate that the Autoscope system had detected a vehicle present (Grade Crossing Safety 1995).

Rozek and Harrison indicated that "on train closed-circuit television" is used to assure crossing safety of French and British trains with grade crossings at 200 kph (125 mph) (Rozek 1988 pg.49).

Odetics, also a California company, has developed Fastrans to send compressed video over phone lines. One version available transmits video over cellular phone lines. This system is currently being used to monitor variable message signs in the San Fernando Valley (Purdom, N. 1995, pg.82). Cellular phone lines have been used in other train-based systems, so it is reasonable to consider this a possible alternative transmission mode for live video of crossings into the cab of approaching trains, as well as to dispatch or another monitoring center.

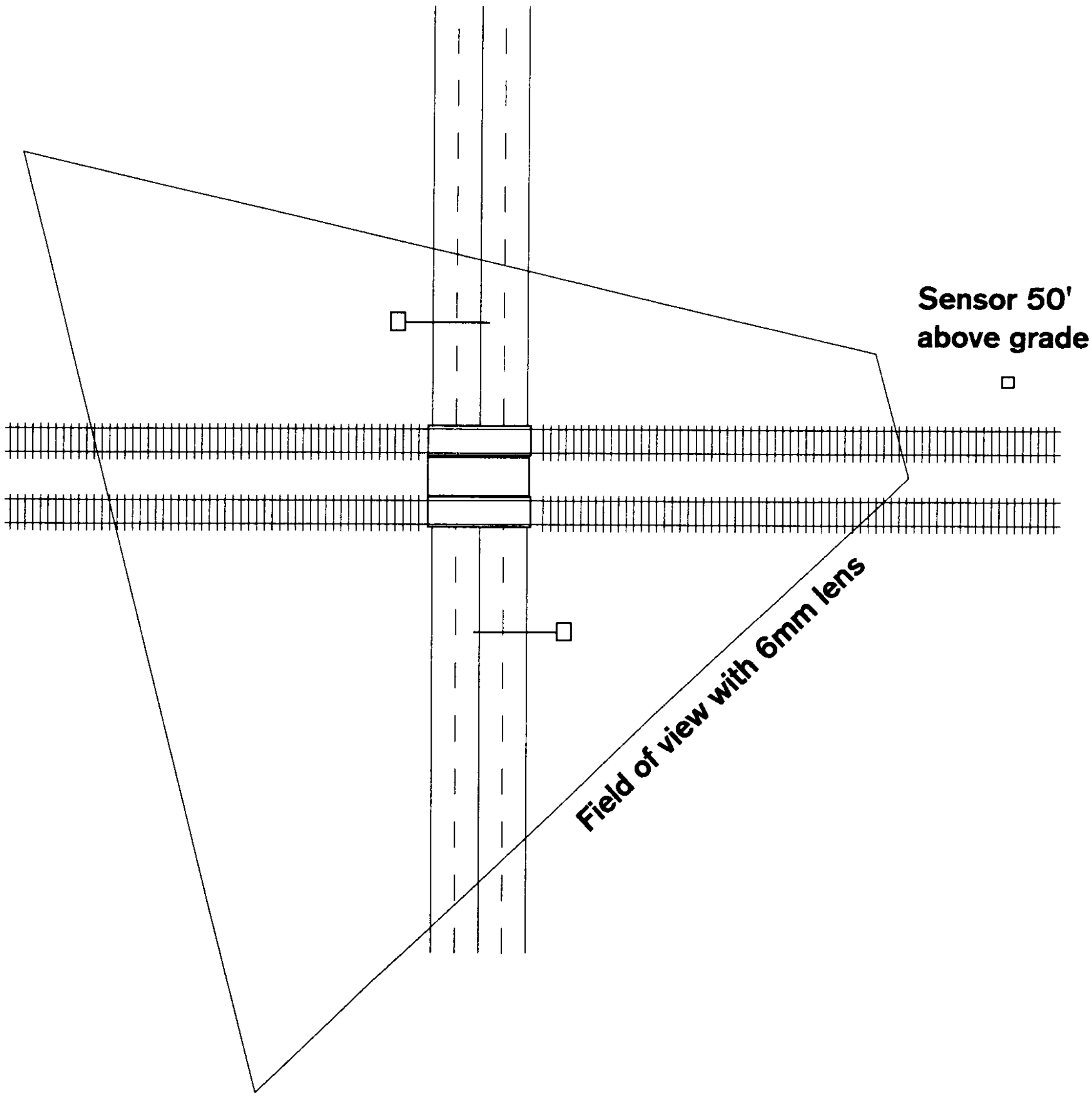

Figure 5.3 — Camera coverage for in-cab crossing video.

5.5.4 Automatic Detection Systems

5.5.4.1 Inductive Loop

Swedish Railways use loop detectors in the crossing to check for the presence of vehicles during a gate-down sequence. Their four-quadrant gates are configured to close approaches but leave open exit lanes as long as vehicles are detected in the crossing. The loops also report crossing status to the wayside check beacon located at the safe stopping distance for approaching trains (High Speed 1994). Loop detectors have also been used in Los Angeles to trigger cameras for crossing enforcement.

In the past, inductive loop detectors have had high failure rates/maintenance needs. The most common causes of failure were improper installation, inadequate sealants, or wire failure (Bikowitz 1985). Careful installation and maintenance can minimize problems, but problem experience and the fixed, inflexible nature of loop installations has propelled investigation of alternatives.

5.5.4.2 Video Image Processing

Another approach to vehicle detection is automatic video interpretation. In contrast to inductive loops, which detect the presence of a vehicle at a particular spot, video detection systems are Wide Area Detection Systems (WADS) capable of monitoring vehicles activity in multiple or extended areas from each camera angle. Flexibility is a key advantage of video detection systems. Different systems offer varied features and options: stopped vehicle detection, remote or on-sight control and redefinition of detection zones for each camera, and live video return over coaxial cable, fiber optic cable, conventional phone, or cellular phone lines (Larson, T. 1995).

Autoscope is the trade name of the video imaging package most widely used in the United States. The VIS feeds video images of the crossing from permanently mounted cameras to a computer. The computer software analyzes the image and in real-time recognizes the presence of a vehicle in user-defined zones. Such a system is called "loop emulation." In addition to its principal use in street/highway applications, the Autoscope system has seen use in Los Angeles as an alternate trigger for photographing highway-rail crossing violations (Bartoskewitz & Richards 1995, pgs 10-11). It has also been included as part of a system which transmits live video of a crossing directly to the cab of an approaching train.

Beyond loop-emulation systems, video detection systems capable of tracking individual vehicles are being developed and installed. In Spain, one WADS that detects and tracks vehicles over an extended area, as opposed to multiple defined detection zones, is the Estación de Visión Artificial (EVA)—artificial vision station. This is a far more complex problem. The added complexity yields benefits in a traffic management setting by generating richer data than loop emulation systems. The processing power required also makes video compression and transmission practical. Image quality trades off against refresh rate, the product of these two being a constant determined by the bandwidth of the particular transmission mode (Rodriguez and Marzán 1995). The added information from such a tracking system probably is not critical to potential use for monitoring crossing status. Comparisons of video quality and transfer rate with other video detection systems might be worthwhile.

Comparisons of reliability of detection over the range of lighting and weather conditions would also be helpful. New companies and expanded capabilities are entering the field, each making strong claims. A recent addition in the United States is PEAK systems. Their software, like the EVA, tracks individual vehicles. Lane County in Oregon currently has one Autoscope controlled intersection but is installing a PEAK system at a second intersection. Their experience may be very helpful in developing comparisons.

About 450 Autoscope systems are in the field. The current, 4th generation Autoscope usually sells in four-camera units for about $4-5,000 per camera. About 400 EVA units from Eliop Tràfico are being installed around Madrid. A unit for a single camera (without the camera) costs $8,000. A two-camera unit with high-speed image compression costs $18,500 (Purdom 1995, pg. 85).

5.5.4.3 Doppler Radar

Video detection systems offer flexibility and wide area coverage, but they can be affected by changes in lighting and by heavy rain, snow, or fog. Doppler radar may offer longer range and greatly reduced sensitivity to changing environmental factors. THOMPSON-CSF working with SAPRR (Société de Autoroute Paris-Rhin-Rhône) has done preliminary development and study of radar based traffic incident detection. The system could analyze both directions of traffic, detecting stopped or slowed vehicles in a range of 100 to 1000 meters. The reported precision was speed reported ± 2 kph and range reported ± 15 m (Lion and Rousel 1995). Though developed for motor vehicle detection, the characteristics of this system suggest it might be most useful in crossing safety as a system for monitoring approaching trains. Rather than constant activation, conventional track circuits could notify the radar system of a train approaching its detection zone. Speed and distance information from the radar could provide information for constant warning time crossing control. With acceptably conservative assumptions about braking efficiency, the radar could also be used to recognize the decision point for an approaching train—the point at which an occupied crossing would require a FSB command be sent to the train.

5.6 Control and Enforcement

5.6.1 Education and Enforcement

Operation Lifesaver is a public education program first introduced in Florida. It deals with educating the public on how to approach and cross grade crossings and also what actions to take if things go wrong. It is now a nationwide program and according to the program officials it has significantly helped in reducing grade crossing accidents

In addition to public education, enforcement is an important part of creating a community sense that one always heeds crossing warnings. Operation Lifesaver includes education for law enforcement personnel on their important role in increasing crossing safety.

Enforcement is also enhanced by photographing, and subsequent ticketing of those who violate crossing warnings. Los Angeles has experimented with both loop and video detectors to trigger a photograph if a vehicle is detected in the crossing once the warning gates are down.

5.6.2 Redundancy

If a vehicle is present in a crossing, an approaching train must stop before entering the crossing. Because neither automatic equipment nor human operators are completely reliable, redundancy is necessary. Appropriate combinations of human and automatic monitoring and control are needed for each crossing. For instance, a video image processing detection system might notify the ATCS of a crossing intrusion. This would trigger a warning to the train operator and, failing a response, would then lead to automatic braking. If the video image were also being fed to a human monitor, it would be possible to override the automatic systems if the detection proved a false alarm. The human monitor might be the train operator, with in-cab video, or the dispatcher, or in a special corridor-safety office created to work with the train operator and dispatcher in this role. Anecdotal information strongly suggests that train operators will find ways to disable automatic equipment if they do not have faith in it. Having an official channel to deal with faulty readings may help in the full acceptance of extending automatic control to crossing safety.

5.6.3 Median Barriers

Another approach to compliance is simply to make non-compliance physically harder. The two-quadrant gates—standard in the United States—leave open a path around them. Median barriers at highway-rail crossings separate the approach and exit lanes. Thus, if a standard half gate is used to close the approach lane, it is difficult to cross over into the exit lane to go around the gate. This approach discourages defeating warning gates while always leaving exit lanes unblocked. To be effective, the median barriers must extend well back from the crossing. To be safe, they must comply with sound design standards for islands and barriers in streets and highways. Islands, providing a standard curb-height barrier, are not safe at speeds above 55 kph (35 mph). Full barriers suitable for higher speed require appropriate shy distance in adjacent lanes, shock absorbing and/or deflecting end treatments, and appropriate signing.

5.6.4 Four Quad Gates

Four quadrant gates fully block the approaches and exits from a crossing. Resistance to four quad gates has centered on the possibility of trapping a vehicle in a crossing. Koester describes the shift away from four quad gates in the United States (Koester 1995). As late as the 1950s, four quadrant gates were common at crossings operated manually by gate tenders. To save costs, railroads began to automate these crossings. Broken exit gates were common and modifying the delay timing of exit gates was not fully satisfactory. Eventually, exit gates were removed uniformly. ITS detection systems can meet the trapped-motorist concern. In Sweden loop detectors keep open the exit paths until a crossing is cleared and further notify an approaching train of an occupied crossing in time for a safe stop. British Rail guards against trapped vehicles with video surveillance of crossings. Intrusion detection components of an ATCS can automatically brake an approaching train if a vehicle is detected in the crossing.

5.6.5 Normally Closed Gates

At very low volume crossings, and especially private crossings, the best arrangement may be to keep crossings closed except when a vehicle requests and is granted authority to open the crossing gate. This is the approach taken by the DB. Though certainly more awkward than a normally open crossing, this arrangement can offer benefits which may appeal to private crossing owners, principally a gain in control over access to their property.

Consider how this might work. Let the request-for-crossing authority procedure include a changeable electronic access code (punched in by phone or perhaps with an at-crossing keypad)—in the manner of a home security unit. If automatic phone technology is used for the communication link, the roadside unit could include a button to call the owner (home, shop—any number or no number might be programmed by the owner). A touch-tone could then allow the owner to remotely authorize a crossing request. Railroad and emergency personnel would, of course, always possess working keys to the crossing.

5.6.6 Traffic Calming

Intelligent transportation systems should be *systems*. Along with the electronics, the more fundamental realities, such as crossing geometry, need to support and augment crossing safety. Speed and inattention are factors in crossing accidents. Various roadway alignment and construction designs, collectively known under the heading of "traffic calming" designs are being used to lower motorist speeds and heighten awareness at critical junctures. It is worth exploring the possibility of using such designs to improve highway-rail crossing safety.

The highway-rail crossing is already a mentally demanding situation for motorist perception and reaction. Any traffic calming design would have to achieve its purpose without adding to the perception reaction burden of the motorist. The goal would be to increase the time available for response to a crossing through the lowering of approach speeds.

Another possible use of knowledge gained in traffic calming would be the design of traffic flow diverters which would bring an overspeed vehicle into a safe, fixed barrier. Normal traffic would be slowed to turn away from the barrier and then proceed to the crossing. Again, constructing a system that is entirely clear to drivers is critical to the safety and success of such a plan.

5.6.7 Crossing Reliability Monitoring

Increasing use of sophisticated crossing technologies creates greater dependence on the constant, reliable functioning of these systems. Automatic monitoring of crossing health may be a key element in maintaining that reliability. The following discussion is based on that of Bartoskewitz and Richards (Bartoskewitz & Richards 1995, pg8).

Railroad maintenance forces must wisely use available labor and budget resources; they are often spread thin. Damaged or defective crossing equipment may be reported by train crews or motorists. Dispatchers relay this information to the appropriate signal maintainer for action. The system is somewhat haphazard and may leave defective equipment undetected and unrepaired for significant lengths of time. To meet these problems, several railroads are investigating automatic crossing monitoring.

One proposal uses cellular phone and computer calling technology to respond to malfunctions detected by sensors at the crossing. The unit might be programmed to notify appropriate authorities, both railroad dispatch and local police, as well as calling on the maintenance forces for service. A Canadian railroad is testing a system in which crossing monitors are linked to a central computer. The computer constantly polls the crossings to determine their operability. Any malfunctions are identified and reported.

5.6.8 Vehicle Arresting Barriers

At train speeds above 175 kph, crossings must fully protect rail movements. The tasks required at lower speeds remain: driver warning and information, intrusion detection, and physically blocking the crossing. At these higher speeds, however, protecting the train is essential. Physically blocking the entrance to the crossing must be done with some form of barrier capable of stopping any vehicle likely to hit it. Such a barrier may be of an energy-absorbing design or of a rigid, non-forgiving type.

5.6.8.1 "FRIENDLY" BARRIERS

Considerable effort is going into design of impact attenuation barriers which can be deployed at highway-rail crossings. In some cases these are seen as acceptable alternatives where grade separation would be called for but landuse and geometrics make it impossible. In such higher volume applications, the likelihood of serious injuries to motorists may justify higher costs, at least up to those of a standard grade separation.

Some designs use a net which drops down or swings in (Figure 5.4). The net is tied to a visco-elastic shock absorbing system. Such a system may present its own geometric problems. A fixed dragnet system designed to stop a 2,045 kg (4500 lb) passenger car impacting at 100 kph (60 mph) requires about 21.3 m (70 ft) of deflection to decelerate the car at no more than 2 g's (*Roadside* 1989, pg.8-17). Figure 5.5 shows minimum stopping distance (deflection) as a function of impact speed for three idealized constant deceleration systems at 2, 4, and 6 g's. In actual systems, deceleration is not constant. Deceleration curves for real systems are strongly dependent on vehicle mass and system geometry.

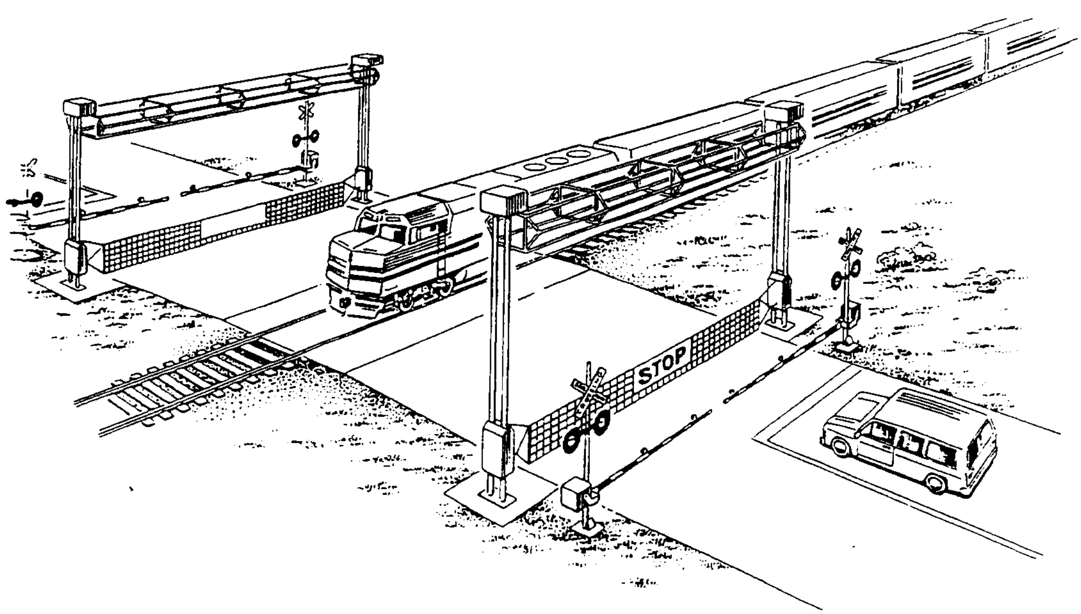

Figure 5.4 — Dragnet crossing barrier.

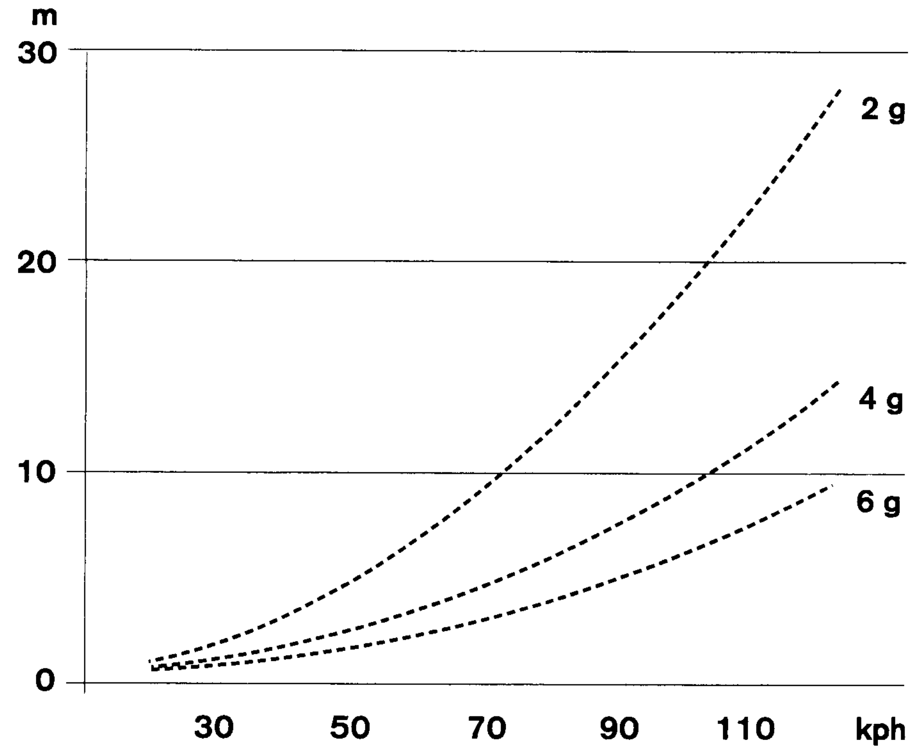

Figure 5.5 — Constant deceleration stopping distance curves.

In other systems, impact attenuation drums roll into place on low dollies. Other systems deploy an energy absorbing wall up from the roadway. All of these systems are designed to protect both the train and the motorist. The protection of wayward motorists, something not afforded by standard crossings today, must be balanced against initial and ongoing costs, deployment time, and turn-around redeployment time and cost following an incident.

5.6.8.2 Rigid Barriers

Using a rigid barrier system would more closely match current expectations for driver safety. Conventional warning signs, passive and active, would precede the barrier. Drivers failing to heed the warnings would hit the barrier with no more protection than they would have hitting a train if the barrier were not there. But the train would be protected. Principal types of rigid barriers are high security barricade and high security bollard designs, each of which can withstand great impacts and continue normal functioning, and crash-rated beam barriers which offer less absolute security but some degree of forgiveness to the impacting motorist (Figure 5.6).

a)

b)

c)

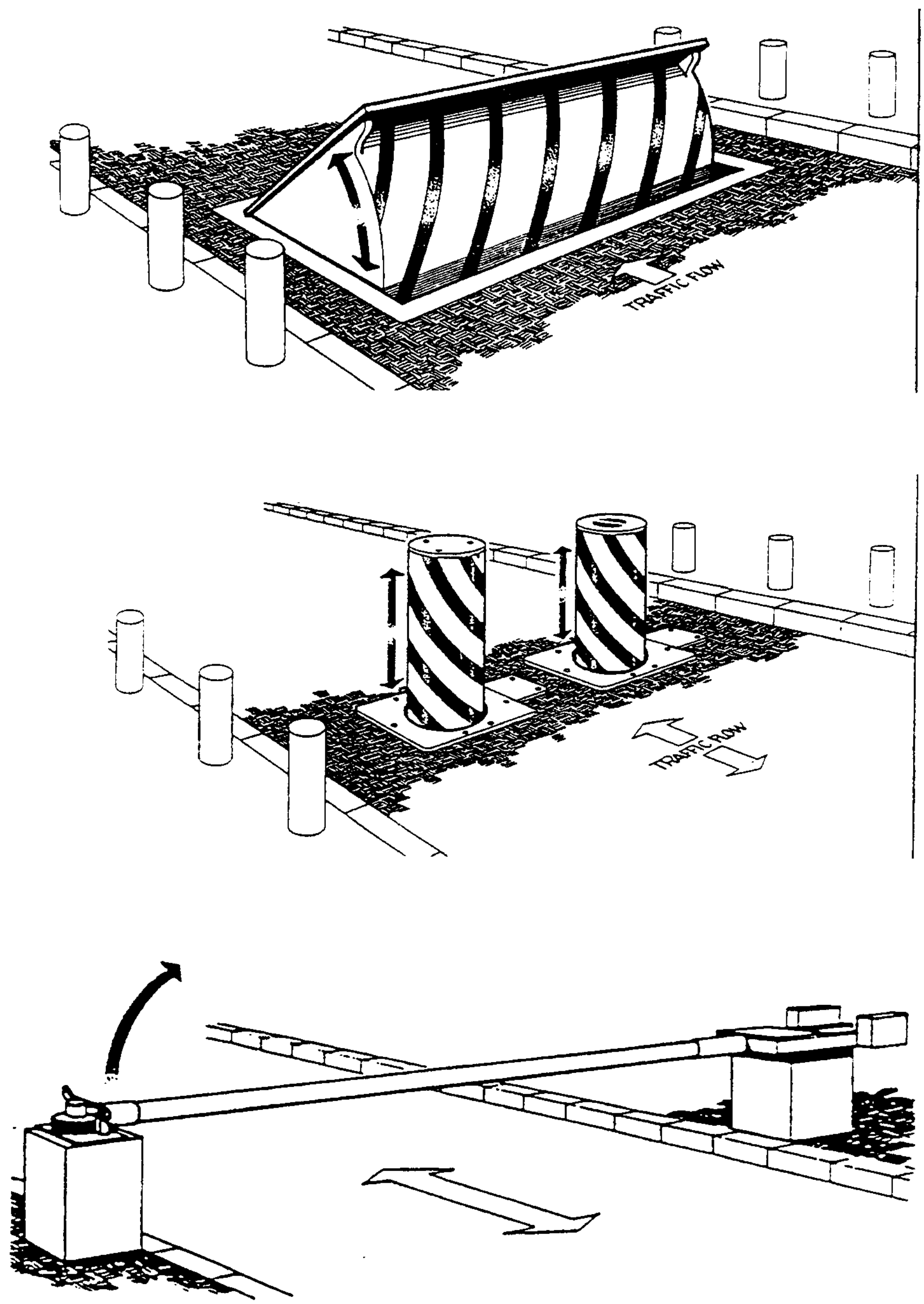

Figure 5.6 — Rigid barriers: a) barricade; b) bollard; c) cable-beam

Crash-rated beam barriers come in two basic forms: vertical lift arms and horizontal gates, which may be rolling, swing, or cantilever. The vertical arm design is much like a conventional warning gate, except that when closed the tip of the gate and its incorporated aircraft cable is locked into a far-side anchor post. This design is available for spans of up to 7.6 m (25 ft). The horizontal gate completely blocks an opening, to both vehicles and pedestrians. This design can span greater openings; for maximum width, two gates can lock to each other.

Crash-rated beam barriers may be quite adequate for grade protection applications where very high speed approaches are unlikely. A typical rating would certify the barrier to stop a 2,700 kg (6,000 lb) vehicle impacting at 55 kph (35 mph). This would be quite appropriate for many small town or village crossings and in more open country if the road geometry forced a speed reduction prior to reaching the crossing. They are widely used at movable bridge approaches. Anecdotal information also suggests their forgiveness—correspondence from B&B Electromagnetic recounts:

> Only a few years ago, the police radioed to a bridge equipped with our TB-7200 barriers to have the barrier closed to stop a vehicle involved in a high speed chase. The vehicle was an old Cadillac. The driver deliberately attempted to crash through the barrier at a high rate of speed (reported to us as in excess of 60 or 70 mph). He was stopped without injury (Mobile Barrier 1994).

5.6.8.3 Warning and Regulatory Considerations

Use of a rigid barrier would require careful attention to warning signage. Drivers must recognize a deadly hazard even when a train is not in sight. In addition to railroad crossings, other instances where roads are intermittently interrupted by deadly hazards include movable bridges and ferry crossings. Typically all of these protect drivers only with warning devices, not energy absorbing systems. Signage for these other instances may offer guidance for rail crossings protected by rigid barriers (cf MUTCD 1988 4E-1,5-6,13-17). Approval for use of rigid barriers at HSR crossings should be sought at the highest level possible—either by enactment of legislation or by decision of the appropriate state transportation commission.

5.6.8.4 *Barriers as Elements of Crossing Systems*

As any gate or barrier is being evaluated for use on high speed rail corridors and in conjunction with ITS monitoring and control functions, several design parameters should be investigated:

- Does the gate/barrier fully close the roadway? At what maximum and minimum widths?
- Will the barrier prevent an impacting vehicle from jumping over?
- What sophistication of control is possible (e.g. can escape segments be separately opened and closed or is it all or nothing deployment)?
- How quickly can the system go from undeployed to deployed and vice versa?
- Crash behavior. What is the arresting capacity? Is it energy absorbing? If so, with what level of deflection?
- Does the system include or lend itself to built-in status detectors able to report operability and any problems in operation? Can it avoid hitting a car during deployment?

5.6.9 Transportation/Grade-Crossing Control Center

Central dispatch centers in the United States may be monitoring and controlling hundreds or even thousands of miles of track. Adding responsibilities for highway-rail grade crossings may overburden the present system. CCTV monitoring of grade crossings and human oversight of warning and protective devices may better be done at a more local, corridor specific level. Such a center might be based on the model of Traffic Management Centers now being used to control signal timing, variable message signs, emergency response, and other congestion reduction measures in large urban areas.

A grade crossing control center would serve as a meeting ground for control of the surface transportation modes. Both rail and highway traffic concerns would be focused on the intersection of these two modes at crossings. Control could be local enough to provide familiarity with the characteristics and peculiarities of individual crossings.

Such a center, operating as a redundant backup or as a primary control agent, would need means to perform all three of the fundamental tasks of grade crossing safety. Train status might reach the center through links to an ATCS system, or from Doppler radar looking up-track from each crossing. Crossing status could be monitored through CCTV with or without VIP automatic detection systems. The center could be given override control of four quadrant gates/barriers to allow escape of trapped vehicles.

Stopping a train when a vehicle is stalled or stuck presents a more difficult set of options. If the center were acting as a backup, and recognized a false alarm, a call to the dispatcher would be sufficient to set in motion the override of automatic train stop systems, allowing the train to proceed through the crossing. But in the event of an actual stopped vehicle in the crossing, time would not allow going through another link in the chain—the dispatcher. The simplest system would give the center a direct line to the train control system allowing them to place the most restrictive aspect on the block containing the crossing. For HSR, such a change in aspect would trigger an audible warning tone and change the cab signals and/or engage the automatic train stop. An alternate approach would be to create a separate communication channel from the center to any train on the track approaching the crossing, to activate a separate in-cab warning system. The cab warning system could have its own tie-in to an ATS. This would have the potential disadvantage of cluttering the cab and presenting one more stimulus which train crews would have to learn to respond to. It might have the advantage of directness, and the rarity of use (as distinct from the standard acknowledgment-required tone) might reduce any tendency to become inattentively reflexive in response—possibly failing to register the seriousness of the warning.

6. CROSSING CLASSIFICATIONS

An understanding of the types of low volume crossings is the first step in designing appropriate treatments. Crossings in the Oregon HSR corridor range from dirt footpaths intersecting the rail line to grade-separated freeway crossings. Of the approximately 237 crossings, 49 are already grade-separated and the remaining 188 are at-grade. Of these 188, 118 are public—including 6 pedestrian crossings. Seventy are private—including three pedestrian crossings. In this report we are concerned only with the low-volume crossings—those with annual average daily traffic (AADT) of 200 or fewer vehicles. Twenty-two public crossings are low-volume. All of the 70 private crossings are assumed to fall into this category.

Many intrinsic and extrinsic qualities can be used to classify the low volume crossings in the Oregon HSR corridor. Among the variables are: crossing ownership, surrounding landuse, operational characteristics of crossings, and crossing user groups. Considering the effects on safety and economics offers a way to winnow the many variables down to a reasonable set of characteristics used to assign appropriate treatments to crossings.

6.1 Ownership/Control

The Oregon Legislature extended PUC authority to all crossings on the HSR corridor, private as well as public (Senate Bill 713, 1993). This transportation function of the PUC has now been transferred to ODOT. Though under one authority, the ways crossing safety improvements will be developed and maintained will vary depending on ownership of the crossing right.

6.1.1 PUBLIC

Public crossings must be designed to a higher standard than may be necessary for private crossings. At best, users can be expected to have no better than average comprehension of grade crossing safety in general. Nor can they be expected to have knowledge of any specific crossing in particular. Higher type designs compensate for lack of control over who uses the crossings. Sixteen public low volume roads and six public pedestrian ways cross the Oregon HSR corridor at grade.

6.1.2 PRIVATE

Private crossings may exist by agreement, without agreement, or by deed right. Sixty-seven vehicle and three pedestrian private ways cross the Oregon HSR corridor. (The following discussion of private crossings is based on Hemmely, 1994).

6.1.2.1 AGREEMENT

Agreement crossings exist where the railroad and a private party have entered into a contract permitting the private landowner to establish a private crossing. These agreements are revocable by the railroad on 30 days notice. Presumably, quality of the crossing and who would pay for improvements would be a matter of negotiation between owners and the railroad once minimum safety standards are met. About 25 crossings in the corridor are agreement crossings.

6.1.2.2 NON-AGREEMENT

As the name suggests, non-agreement crossing have been established by private landowners without permission from the railroad. In such instances, it is the right and duty of the railroad to defend its property rights against such open claims of competing rights. The Southern Pacific in the Willamette Valley has been reluctant to pursue closing of these irregular crossings. Approximately 36 private crossings exist without contractual agreement. In a third of these cases, the crossings have been in existence for more than ten years. This open use by adjacent landowners for ten or more years may well meet the requirements to establish a prescriptive easement. These landowners' rights of use could be removed only by agreement or condemnation—with just compensation. Negotiations on improvements to any non-agreement crossing may need to start with regularizing the crossing in one way or another—by agreement or court action. Again, this is first an issue between private parties.

6.1.2.3 Perpetual Right

In four cases, property owners have deeded access to the railroad for its right-of-way with the stipulation that the owner can establish a crossing lasting into perpetuity as a property right. Here the property owners have the strongest hand in dealing with the railroad—but as with all private crossings the issues are first between private parties. The state, through ODOT, should only step in with its power of condemnation as a last resort if needed to create a safe HSR corridor.

6.2 Land-use Access

Public crossings may be categorized by their surroundings as urban, small town, or rural. Private crossings may have more particular and limited uses.

6.2.1 Public

Urban, small town, and rural settings affect driver expectancy and behavior. The settings may also create differing constraints on alternate access and emergency services. Many urban, small town, and rural effects will be reflected in other factors, e.g. density of crossings and AADT.

6.2.2 Private

A rough breakdown of private crossing uses in the Oregon HSR corridor is given in Table 6.1. Different uses make different demands. Agricultural crossings may be field access needed only at a few times during the year but the crossing may need to accommodate a tractor pulling a harrow. Residences/farm driveways may have few or many daily trips depending on the family and/or the farm operation. Businesses crossings may serve primarily employees, or they may be quasi-public crossings for a retail operation. Figure 6.1 shows how these uses are distributed along the corridor.

Table 6.1 — Count of private crossings by landuse type.

Crossing Type	Count
Agricultural Crossing	26
Residence/Farm Drive	24
Industrial	12
RR Yard	5
Fire	1
Pedestrian	2
Total	70

6.3 Crossing Geometry and Traffic

Crossing geometry and traffic, both train and highway, provide primary measures of crossing operation.

6.3.1 Number of Tracks

Multiple tracks present a particular hazard when a stopped or slow moving train on a near track blocks motorists' view of another train on a farther track. Five

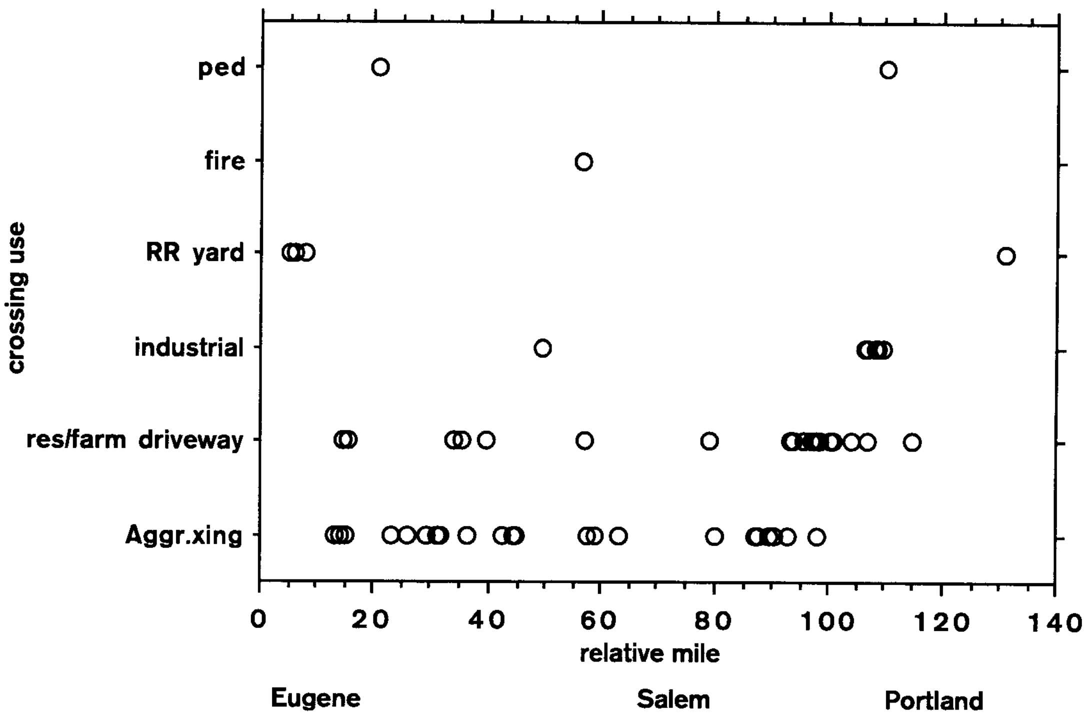

Figure 6.1 — Distribution of private crossings by landuse type.

of the sixteen low volume public road crossings have multiple tracks. All of the private crossings are over single tracks, though some may be near divisions to double track.

6.3.2 Number of Trains

The greater the number of trains the greater the risk exposure. Some switch engine traffic increases the number of trains in the urban areas of the corridor, but the low volume crossings all have essentially the same number of trains. Currently 16 to 20 trains daily use the SP mainline down the valley. Merger with the Union Pacific and a trend toward smaller freight trains might significantly increase this number in addition to any added passenger trains. At whatever level, the number of trains is likely to remain consistent from one crossing to another through the length of the corridor.

6.3.3 AADT

Highway traffic is the other direct risk exposure factor—more vehicles present more opportunities for accidents. AADT also is a direct factor in figuring the delay caused by crossings. Higher traffic volumes require higher levels of service—very low volumes may allow significantly greater levels of inconvenience at crossings. The 22 low volume, at-grade public crossings in the corridor include 16 roads and 6 pedestrian only crossings. Of the 16 road crossings, 3 may be classified as extremely low volume with AADTs of 20 or fewer vehicles. Figure 6.2 shows the distribution of AADTs for the low volume public crossings. Traffic volumes are not at present available for private crossings.

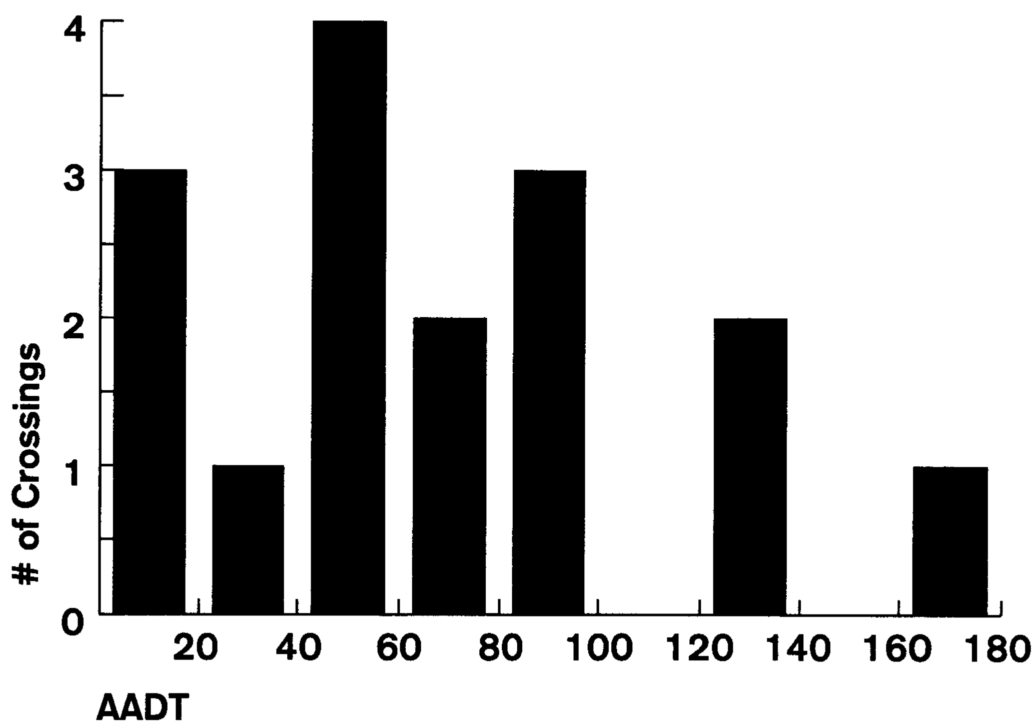

Figure 6.2 — Low volume public crossing counts by AADT.

6.3.4 Crossing and Approach Geometry

Oblique angles increase difficulties in seeing and interpreting possible conflicts at crossings. High speed trains may travel twice the speed of standard freight trains in the corridor, requiring much longer sight distances up and down the track to allow adequate visual warning of train approach. Clear lines of sight as vehicles approach a crossing are important with passive crossing controls, but much less so with active control. The approach of the highway to the crossing may affect the speed with which a negligent driver might drive through warning gates—this is important in deciding on the energy absorbing capacity of barriers where the train must be protected. Many of the crossings in the corridor occur where the railroad closely parallels Highway 99 leading to extreme vertical curves (humps) and little refuge space between the tracks and the main highway.

6.3.5 Crossing Density

The number of crossings along a given length of track is of particular interest when looking for relatively painless opportunities for crossing consolidation. Higher crossing densities may offer alternate access or suggest building a frontage road.

6.3.6 Train Speed

Though we are looking at crossings for high speed trains, some areas may be constrained without exceptionally high expenditures to straighten and otherwise improve the track. For example, the SP mainline is on a curve through the town of Jefferson, with a bridge at one end of the curve. Bringing trains up to the highest speeds here could be very costly.

6.4 Users

Passenger autos can be assumed at all crossings except those for pedestrians only. Trucks, buses, and farm vehicles may present special problems, requiring adequate widths between gate supports, acceptable vertical curvatures to prevent bottoming out, adequate refuge space between tracks and stop controlled intersections, and allowance for greater times to cross and clear tracks. Where the crossing is to a field used for livestock, animals must not be allowed to stray onto the tracks.

Pedestrians and bicyclists present other questions. When must specific pedestrian treatments be employed along with vehicle related controls? Are bicyclists at a crossing likely to operate as vehicles, as pedestrians, or both? What is required by the Americans with Disabilities Act (ADA)? Can a wheelchair passable crossing still safely accommodate the dynamic envelope of a high speed train's wheels? These are important and largely unexplored issues, and beyond the scope of this report.

6.5 Accident History

A crossing which has once had an accident is more likely to have additional accidents—if nothing changes. The most significant change is an upgrading of a crossing from passive to active warning. More subtle, but also important changes may arise from changing land use in the area, changes to the highway network in the region of the crossing, or changes in railroad operations (e.g. scheduling, use of sidings). Five of the low volume public roads have recent accident history.

6.6 Selecting Critical Design Categories

Each grade crossing must be treated individually, but a few broad categories shaped from all of these variables can provide a useful starting point. Some of the information needed to place crossings in one category or another is already available, more will need to be gathered.

Safety and economic factors are the core of grade crossing cost benefit analysis and offer a useful filter for understanding grade crossing characteristics. First it should be noted that the different characteristics do not all represent independent variables; for example, AADT for field access will be vanishingly small, for towns perhaps in the hundreds.

Grade crossing accident prediction models weight different factors according to their effect on safety. The data these are based on in this country do not, of course, come from HSR operations. The maximum safety measure considered is also only the conventional two quadrant gate with flashing lights. Despite these limitations, such models are a good way to gain understanding of which factors are most critical in the safety performance of crossings.

The *Rail-Highway Crossing Resource Allocation* Procedure is the FRA's preferred model for crossing safety analysis (*Rail-Highway*, 1986). The most important factors in this model are the level of crossing protection, AADT, the number of trains daily, and the number of tracks crossed. An additional factor uses the accident history of individual crossings to account for other potentially significant factors which are not part of the crossing database (e.g. proximity to a tavern).

6.7 Recommended Design Categories

A limited set of primary design categories allows focus on the principal crossing protection needed for each category. These primary categories are given in Table 6.2. Within the different categories, individual factors such as the need to contain livestock may further shape the crossing treatment. This set of primary categories forms one axis of the treatment matrix presented in the following chapter.

Table 6.2 — Primary crossing categories.

Category	Use	AADT	Train Speed
Special Minimum	private	less than one	up to 175 kph
Basic Minimum	private public	<= 200 (assumed) up to 20	up to 175 kph up to 175 kph
Basic Public	public	<= 200	up to 175 kph
Higher Speed-Basic	private public	<= 200 (assumed) up to 20	up to 200 kph up to 200 kph
Higher Speed-Public	public	<= 200	up to 200 kph

These categories reflect a combination of risk factors and level of service requirements. In most cases these two qualities move up the scale together. Extremely low volume crossings present less risk, and greater inconvenience can be tolerated by the small number of users. Conversely, higher volumes increase risk and require greater attention to guidance and delays. The first three categories are for train speeds up to 175 kph. The latter two categories are for speeds up to 200 kph and reflect the necessity of protecting trains from probable derailment in the event of an accident.

6.7.1 Special Minimum

The special minimum category is reserved for rarely used private crossings with no complicating safety factors. Some farm field access points may need to be retained, though any higher type treatment cannot be justified for the small risk involved. These crossings

- have tight control on who uses them,
- only need to be reached on a few days during the year,
- have excellent sight distances, and
- train speeds not higher than 175 kph.

6.7.2 Basic Minimum

The basic minimum applies to all other private crossings and as a special case to the three extremely low volume public crossings in the corridor. Note that these other private crossings represent a very wide spread of characteristics—no one treatment will be most appropriate for all of them. But all can be placed under a required minimum standard. The private parties themselves will be the best judges of whether a higher type treatment, with a higher level of service, is justified for their own particular crossing.

6.7.3 Basic Public

This category is for public roads where train speeds do not exceed 175 kph. As a public facility, level of service and very clear guidance to motorists become very important.

6.7.4 Higher Speed-Basic

This category recapitulates the Basic Minimum. In this case, the higher train speeds will also require treatments clearly focused on protection for the train.

6.7.5 Higher Speed-Public

Again, this category recapitulates the Basic Public, but with the paramount need to protect the train. That need and the higher demands placed on public crossings make this category of crossings quite challenging.

7. RECOMMENDED CROSSING TREATMENTS

The following guidelines are largely in accord with and extend the recommendations of the FRA/FHWA *Action Plan* (Table 2.3). We assume that medium and high volume roads will be grade separated or treated in other ways beyond the province of this report. For all treatments, closure/consolidation or grade separation is the first recommendation where possible. This might be accomplished by providing alternate access, creating frontage roads, arranging land trades, or outright purchase of lands. Above 200 kph all crossings must be closed or grade-separated. The understanding of the types of low volume crossings provided in the previous chapter provides the starting point for assigning appropriate treatments to crossings.

The *Action Plan* states the need for new approaches to private crossings: "FRA has traditionally taken the position that private crossing matters should be settled by the private parties involved. However, from a safety perspective, this approach has proven inadequate" (*Rail-Highway* 1994, pg.12). The Oregon State Legislature recognized the need for change and gave the Public Utility Commission the same authority over private crossings on the high speed rail corridor as it exercised on all public crossings (Senate Bill 713, 1993). As a transportation function, this authority has now been shifted to ODOT.

The *Action Plan* also suggested a treatment: "The feasibility of placing gates with remotely activated cipher locks at private crossings will be investigated and possibly demonstrated." Such as system would require calling the dispatcher to enable unlocking the gate. "The gate would be interlocked with the railroad's signal system" (*Rail-Highway* 1994, pg14).

A key element for such private crossings is that the crossing is closed by default, and opened only on request when safety is assured. As discussed in Chapter Five, a Traffic Management Center would provide an alternative to burdening the train dispatchers with handling crossing requests.

Public crossings require a higher level of guidance, control, and convenience for users. Except in the case of extremely low volume crossings, public crossings should be open by default and close only when necessary as trains approach. Safety for higher speed trains will require earlier advance gate closing.

7.1. Primary Protection Elements

Figure 7.1 presents a matrix of primary crossing protection elements and the five basic crossing categories presented in chapter six. The following section presents guidelines for these primary elements. Key system elements for more than one treatment level, e.g. use of a Traffic Management Center, are discussed where first encountered.

R = Required O = Optional	speed < 175 kph			175 kph < spd < 200 kph	
Categories/ Treatments	Special Minimum	Basic Minimum	Basic Public	Higher Speed-Basic	Higher Speed-Public
Close Crossing	O	O	O	O	O
Private Gate	R	-	-	-	-
Remote Lock Gate	O	R	-	-	-
Four Quad Gate	O	O	R	-	-
Remote Lock Barrier	O	O	-	R	-
Automatic Barrier	O	O	O	O	R
Grade Separate	O	O	O	O	O

Figure 7.1 — Primary crossing treatment matrix.

The required treatments are intended as minimum standards. Crossings which fit a lower risk and LOS category may, as an option, be given treatment appropriate to a higher demand category. For example, a business owner served by a private crossing might wish to treat the crossing as though it were a public crossing—the greater expense being justified by the greater convenience. The minimum standards provide a baseline for negotiations over distributing the costs of improvements among the state, railroad, and private land owners. Higher type treatments would presumably be paid for in larger measure by the party requesting the higher treatment.

7.1.1. Private Gates

Seldom used crossings with no complicating factors do not warrant sophisticated and costly treatment. At the same time, use of such crossings must not be casual. For Special Minimum crossings, a simple, lockable gate is adequate. The gate may be chosen and installed by the crossing owner. It should normally be left locked (this could be as simple as a length of chain and a padlock). Extra keys should be provided to area emergency service providers and to the railroad. The gate should be set back at the edge of the railroad right-of-way. Users of the crossings must be instructed to wait if any train is in sight at any distance—judging train type and speed is too difficult to chance. Violations of this instruction—repeated crossings in sight of a train—could be grounds for ODOT to require upgrading the crossing to the full Basic Minimum treatment.

7.1.2 Remote Lock Gates—TMC Control

Remote lock gates are the type of control mentioned in the *Action Plan*. The gate is normally locked. The lock is controlled remotely by railroad dispatch or from a Traffic Management Center, either by phone line or radio. The following treatment discussions assume a TMC, but the procedures and systems would be essentially the same if created as part of the railroad dispatch system.

At a remote lock gate, the user must call the TMC to receive clearance to cross. If adequate time is available, the TMC will unlock the gate. Gates could be automatically raised and lowered, but in most cases will be manually operated by the user. It may be desirable in some locations to provide phones on either side of the crossing connecting directly to the TMC but the pace of cellular phone service availability and acceptance may make this unnecessary. Signs at each crossing will identify the crossing by number and give the number to dial for crossing clearance/ gate lock release.

7.1.2.1 User-System Interface

The basic elements of a standard gate-opening request are shown in Figure 7.2. Normally the call will be handled automatically with a minimum of input from the crossing user. After dialing the TMC, the user punches in the number of the crossing and the four-digit security code created by the crossing owner. If adequate clear time is available, the gate is unlocked and the user notified to proceed. Otherwise, the computer will give an estimate of time until the crossing will be clear. Would-be users of the crossing will be able to hear a message recorded by the crossing owner. Staying on line will connect the user through to a human at the TMC.

The owners will also be able to call a separate phone number to make changes. They will be able to change the recorded messages available to users. They will be able to change their master codes (which enable these changes) and to create new access codes to allow use of the crossing. In this way, a farmer could give a working access code to someone who needs temporary access; after they are done, the farmer could then remove that code. Emergency service providers and the railroad will have permanent access codes.

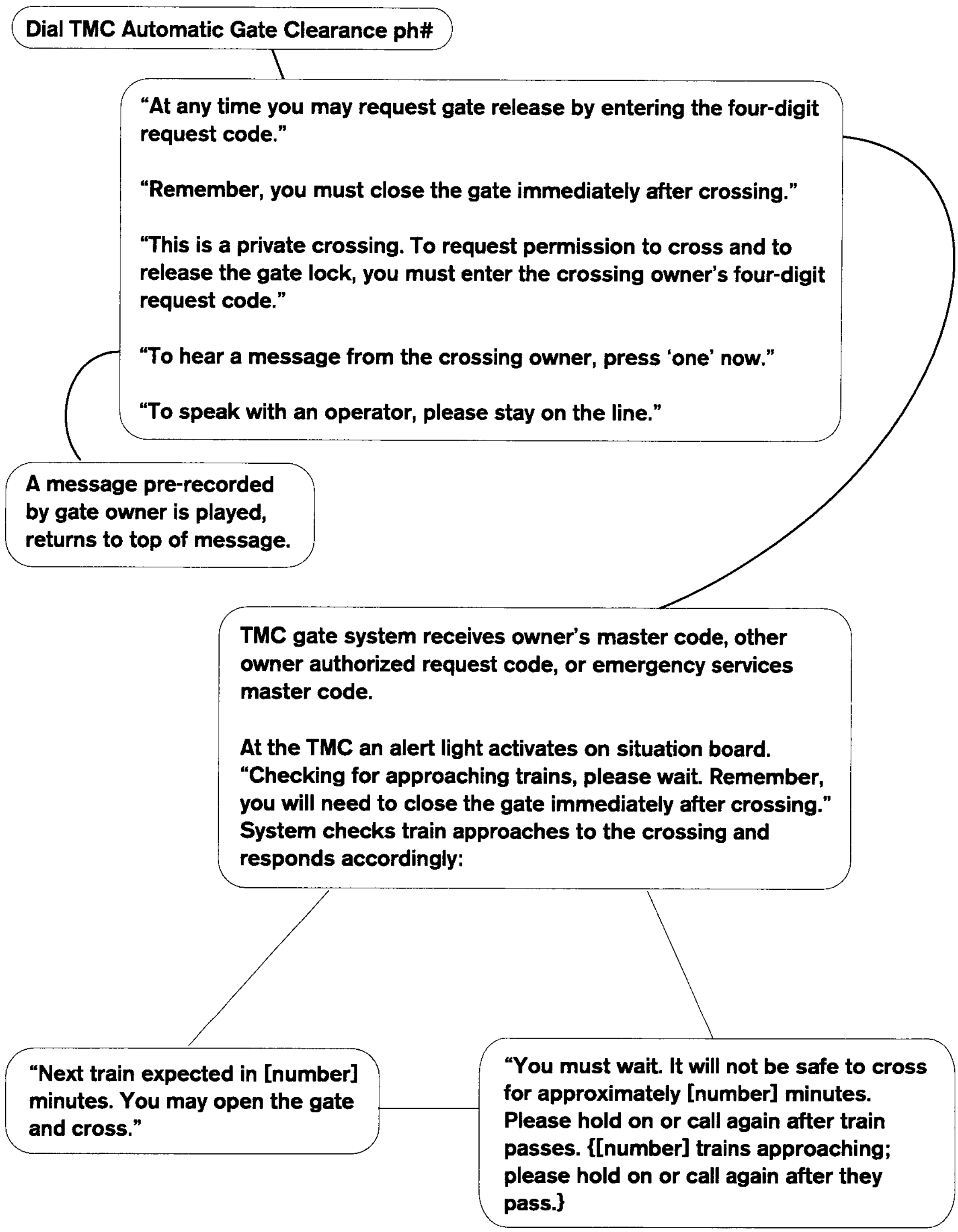

Figure 7.2 — Automatic gate unlock request procedure.

7.1.2.2. TMC

The TMC will be responsible for crossing safety somewhat the way air traffic control is responsible for safety at airports. Trains and road users both need to occupy the same space at a crossing—the TMC must assure that they are never both in that space at the same time. Most of the work will be monitoring of automatic systems. Train locations, velocities, and types will be constantly available from data links to GPS units on the locomotives. When a request for gate opening is received, a computer will check for approaching trains, calculate their decision points with respect to the requested crossing, and determine if enough clear time is available to allow the gate to be unlocked.

A situation board or display will show the whole corridor. Train movement will be shown in real time. All crossings will be indicated as open, closed, or request-pending. Alerts will sound if an opened gate is not closed again within a reasonable time. A phone icon or indicator will display next to the crossing when a user holds on to speak with a human.

The TMC operators will have phone numbers of crossing owners to call if a problem appears. For instance, if a gate is left open, a call to the farmhouse will often find someone who can contact the people working the particular field. The operators will also have a direct radio link to the locomotive cab. A gate not closed in a timely manner would cause the computer to send a caution to approaching trains—requiring them to slow before reaching the high speed decision point then proceed with caution at a speed based on clear sight distance to the particular crossing. The computer database will store and process the information needed for correct timings and caution approach speeds for each crossing.

7.1.2.3 Timing

Current active crossing timing is based on the time needed to clear out a crossing once the warning device is activated. A twenty second lead time is intended to let vehicles in the crossing have time to get out of the crossing. The possibility of a stuck vehicle is small enough to simply accept that risk. The timing is not based on train braking distances. A standard freight train traveling 100 kph will take more than four kilometers to stop—braking for minutes rather than seconds. (Typical braking distances, from which braking times are calculated assuming constant deceleration, are from Ullman and Bing, 1995.)

The greater risks of HSR, including the even greater difficult of accurately judging train approach speeds, justify crossing timings based on train braking distances. These are primarily a function of the train type—its mass and design braking capabilities, train maintenance—the actual effectiveness of all the brakes, and the train speed. The much lower mass of higher speed passenger train sets allow them to brake in much shorter distances than freight trains at any given speed. At 130 kph a passenger train can stop in about 43 seconds of full service braking. At 175 kph that rises to about 65 seconds and at 200 kph the braking time needed is about 76 seconds. Those are the times needed once the brakes are applied. Crossing clearance, communication, and reaction times must also be considered.

We discuss crossing clearout times for automatic gate systems below. For a manually operated, remote lock gate, clearout time includes leaving the vehicle, opening the first—near—gate, opening the second—far—gate, returning to the vehicle, driving through, leaving the vehicle, closing the first gate, and closing the second gate. Time trials with a prototype will be needed, but for the moment an allowance of 120 seconds is reasonable.

Communication time includes the time needed for the TMC to recognize a problem and send appropriate instructions to the train cab. In the case of remote lock gates, this is a cushion on the clearout time. The question is, how much more than the 120 seconds do we want to allow before a failure to detect a closed second gate generates an instruction for a critically close train to stop. The reactions in this case are all automatic, no human interpretation or actions are immediately required. Ten seconds is an appropriate allowance. This cushion time might also be customized to account for crossing peculiarities. For instance, where trains have come out of slower sections and are accelerating, a longer time would correct for the increasing braking time requirement as the train speeds up.

The actual braking time, added to the clearance time, the communication/ adjustment time, and the standard eight seconds in-cab reaction time totals to the clear time needed to unlock the gates. For a train approaching at 175 kph, this would total to about three and one quarter minutes. If all goes well, a critically close train would actually pass by in less time than this, as it would not be slowing to a stop. The TMC calculations for a gate release request are as follows:

1) Using signals from the GPS/PTC system, locate the trains nearest the crossing approaching from each direction. Get the train type and speed. The following steps apply to each train (a closer train in one direction may be slower; the farther train in the other direction might be the critical case.)

2) Calculate the actual braking distance required for a full service stop, based on train type, speed, and an assumed brake derating (Ullman and Bing used a 25 percent derating, which may be high). This distance out from the crossing is the train decision point at which full service braking must begin to stop the train before it enters the crossing.

3) Multiply train speed by the clearout, communication/adjustment, and reaction time allowances to find the distance the train will travel during crossing use.

4) Add this travel distance to the train decision point distance. If the train is at or closer than this distance, deny the gate release request.

5) If all trains are a safe distance away, permit the crossing; unlock the gates.

6) Monitor train position and speed, updating train decision point. If train reaches decision point and both gates are not closed, signal cab for full service braking.

7) If clearout and communication times have passed without both gates closed, approaching trains not yet at a critical point may be instructed to slow before reaching their current-speed decision point. Based on crossing specific sight distance data, the computer will instruct the train to slow to a speed at which the crossing can be clearly seen eight seconds back from the train decision point for the slower speed. Automatic train control would greatly aid this process.

8) When both gates are closed, the TMC signals the train to continue at normal speed.

7.1.3 Four Quad Gates—Intrusion Detection

Basic Public crossings should be treated with four quadrant gates. These are simply conventional railroad crossing warning gates, but arranged to completely block access to the crossing. They are dimensioned, painted, and have descent rates as specified for crossing gates in the MUTCD. Four quad gates prevent impatient drivers from slipping around by crossing over into opposing lanes. Intrusion detectors will prevent trapping vehicles in the crossing.

Timing of the gates will differ from conventional in two aspects. The activation of the crossing gates will be based on train braking as discussed above. The closing of the second set of gates—those blocking the exits from the crossing, will be delayed and can be prevented if a vehicle is still in the crossing.

7.1.3.1 Activation Timing

Activation timing of four quad gates is based on the same motivation as discussed above for remote lock gates—clearance is given to occupy the crossing to road users or trains, but not both at the same time. To allow road users in the crossing when a train has passed the point at which it could stop before the crossing would violate this principle. Train decision points will be calculated for four quad gates in the same way. The question of clearance and communication/ adjustment times is, "How early must we activate the gates to assure that the crossing is clear before the train reaches the decision point plus reaction distance?"

The current standard for crossing clear out time is 20 seconds. This has been questioned by MacDonald (1995). He points out that the timing of crossings is based on a California standard established in 1927. Much larger trucks operate now and, at crawl speeds, they may require more than 20 seconds to clear a crossing. Quad crossings will have intrusion detectors (discussed below), allowing notice to trains to slow if necessary. Basing activation on train braking time also gives a much larger safety margin than conventional timing. However, it is also critical to the success of passenger rail that it operate on time, that it not experience unanticipated slowing because a crossing is not cleared out in the anticipated time. Given this need, extending the clearout time to 25 seconds is reasonable. CFR 49 Parts 234.223 and 234.225 set minimum times.

Adjustment/communication time for quad gates may be zero. As a normally open crossing, public or quasi-public in nature, and fully automatic in operation, extra time need only be built in to account for individual crossing peculiarities. As above, changing train speeds approaching the crossing will continually change the actual train decision point—adjustment time can allow for that.

A train approaching at 175 kph with a full service brake stop distance of about 1.5 km would cover that distance in 30 seconds at speed. The gates in this case would need to come down: 30 seconds travel time from the decision point, plus 25 seconds clearout time, plus 8 seconds reaction time—a total of 63 seconds before the train arrives at the crossing. The actual passing of the train would only take a few seconds. This lead time before the train arrives is much longer than current practice. Three things contribute to its acceptability:

1) this treatment is for low volume roads;

2) it is enforced—the closed exit gates will prevent impatient motorists from driving around gates and through the crossing;

3) motorists will be informed—variable message signs (discussed below) will let them understand that the long delay is not a malfunction.

The gate activation point, then, is the distance to the computed train decision point, plus the travel distance of the clearout time, reaction time, and any adjustment/communication time. The control sequence is:

1)When a train passes its gate activation point for a particular crossing, that gate activation sequence begins. The status display in the TMC shows this and subsequent changes.

2)The train speed is monitored and the train decision point continually updated. If the train reaches its reaction point—eight seconds travel from the current-speed decision point, and all gates are not closed, a full service brake instruction is sent.

3)When the all-gate-closed signal reaches the TMC, the train is instructed to resume normal operations.

4)When the TMC detects (from GPS system) that the train has passed the crossing, the gates all open at the same time.

7.1.3.2 Intrusion Detection

The main objection to four quad gates has been the fear of trapping vehicles in the crossing. Intrusion detection will remove this problem. Gate activation will start with lowering the gates which block the approach lanes. In normal circumstances, the gates which block the crossing exit lanes will begin to lower only once the approach gates are fully down. If a vehicle is detected still in the crossing, the approach gates remain down but the exit gate for the occupied lane does not descend until the vehicle is clear of the crossing. Detector status will be relayed to the TMC responsible for the safety and control of the crossing.

Video image processing, inductive loop, infrared, or sonar detectors could be used for intrusion detection. Inductive loops must be designed to operate reliably in the electrically active area around the tracks. Infrared and sonar detection would not have this problem, but as far as we know have not yet been tried for train crossing detection. None of these technologies give more information than presence or absence of intrusion. Video image processing has been used for intrusion detection for photo enforcement (Bartoskewitz and Richards, 1995). It also has the advantage of placing cameras at the crossing which could be used for human monitoring of crossing status. Such monitoring is not required as part of this treatment for Basic Public crossings, but would be necessary if train speeds are to be further upgraded. Using video at this stage can be thought of as an incremental approach toward the second stage of higher speed rail.

7.1.4 Remote Lock Barrier—Protecting the Train

Higher Speed-Basic crossings will operate in the same way as Basic Minimum crossings, but with a definite focus on protecting the train from any collision. Barriers will take the place of gates. The *Action Plan* identifies 110 mph (175 kph) as the speed above which a collision is likely to cause a derailment. We have not been able to locate any study upon which this is based. All of our treatments for HSR crossings are based on avoiding any collisions. The treatments described in the previous sections are based on excellent information and moderate enforcement. For speeds above 175 kph, additional enforcement will prevent accidental or willful recklessness from endangering the train at crossings.

A barrier, in this case, is just a type of gate designed to contain a crash of given energy within a known deflection. In other words, if a vehicle hits it, it will bend but not break. For most private crossings, a relatively simple cable-reinforced gate will be adequate. The gate contains one or more lengths of aircraft arresting cable—the kind used to stop jets on landing on carriers. It is hung on a solid anchor and when closed locks to another solid anchor. The arrangement is such that the ends of the cable are locked to the solid anchors on each side when the barrier is closed. Such gates do have some give when struck, but they cannot be considered friendly. Barrier design needs to stop the vehicle, neither letting it cut under or jump over. The width of the barrier would depend on the needs of the particular crossing owner—some agricultural implements may require a 24 foot clear opening.

In some instances a still more formidable barrier may be called for. See Section 5.6.8 above for descriptions of various barriers and Section 7.1.5.1 below for a decision criterion. Timing and operation are the same as for the remote lock gate.

7.1.5 AUTOMATIC BARRIER—VIDEO MONITORING

The highest treatment type for low volume roads combines barriers to protect train movement with an additional layer of checks against trapping vehicles. As with four quad gates, crossing status will show in the TMC. For these Higher Speed-Public crossings, a video image of the crossing will also come up at the TMC when the gate and barrier system is activated.

7.1.5.1 BARRIER/WARNING GATE ARRANGEMENT

At this level, with significant, public-use volumes, barriers cannot be used as their own warning. The public is used to relatively flimsy gates at crossings, which they do at times drive through. Barriers themselves will need warning gates.

The distances out from the tracks will depend on the type of barrier used. A highly rigid barrier, e.g. steel and concrete bollards, can stop a small truck with virtually no deflection. "Friendly" barriers, ones capable of decelerating a vehicle at only a few gees, have much larger deflections—on the order of 20 m. Crash-rated cable barriers as described above fall somewhere in between. The space available may be one key factor in choosing a barrier type. The other key question is, "How much energy might hit the barrier?" How large a vehicle at what speed must be expected when planning adequate protection for the train? A useful approach would be to survey the traffic type and speed at each crossing. Estimates of vehicle mass would allow generating a set of energy levels on the approach to the crossing. The 80th percentile energy level could then be used to set the protection needed for the crossing.

Whatever type of barrier is selected, it will block the full width of the roadway. The warning gates before the barrier can be standard, approach lane, gates. Signage will indicate the barrier as well as the tracks which it is protecting.

7.1.5.2 Timing

Timing for the automatic barrier system will be essentially the same as for four quad gates. The barriers fit into the pattern in the same place as the escape lane gates. At activation, the lights flash, the warning gates come down, and the intrusion detection system waits for the crossing to clear. Once clear, the barriers are deployed. This allows the all-gates-closed signal that allows the train to proceed through the crossing.

The gate activation point again is the distance to the computed train decision point, plus the travel distance of the clearout time, reaction time, and any adjustment/communication time. Clearout time will likely be longer—the crossing is stretched out over a greater distance and some barrier types may take longer to deploy than a simple gate lowering. It will have to be calculated as part of each crossing design. Again, variable message signs will reduce public anxiety over the long crossing closure lead time.

7.1.5.3 Video Monitoring

In addition to intrusion detection, the crossing will be watched by human operators at the TMC. Activation of the gate/barrier system will bring up the crossing video image on a monitor at the TMC. Intrusions which prevent clearout in the allowed time will add visual and audible alert signals to the display. The same automatic systems as for four quad gates will signal full service braking to the train if needed. The TMC will be able to advise the train crew and override any automatic systems if it is clear that a false detection is the problem. The TMC will also have direct input to variable message signs and audible message systems at the crossing. The video signal from the crossing could also be sent directly to the cab of approaching locomotives.

7.2 Other Treatment System Elements

Many support elements are required for information, guidance, and control at crossings. Some of these are conventional, well defined, and familiar. Others are newer and still evolving.

7.2.1 Standard Elements

Standard crossing elements are based in statutes and the MUTCD and are already incorporated in crossings serving normal freight and passenger trains.

7.2.1.1 Stop Sign

ORS 763.130 requires stop signs at all private railroad crossings, unless such a stop sign would itself create a greater safety hazard. Stop signs will still be appropriate for Special and Basic Minimum and Higher Speed-Basic treatments. A closed gate is cause to stop. At crossings where Basic Public and Higher Speed-Public treatments are used, stop signs are not appropriate.

7.2.1.2 Advance Warning Sign

Advance warning signs are traditional yellow diamond warning signs with a pictogram of a railroad. An advance warning sign specifically for HSR crossings is currently under consideration by MUTCD. Advance warning signs are appropriate for all public crossings. Private crossings not visible from an adequate distance also require advance warning signs.

7.2.1.3 Pavement Markings

Standard pavement markings as set forth in the MUTCD are appropriate for all treatment categories wherever the approach is paved.

7.2.1.4 Flashing Lights

Flashing lights are required for Basic Public and Higher Speed-Public treatments. Their function and design are set forth in the MUTCD. Note that for Higher Speed-Public crossings, the flashing lights are part of the advance warning gate system. They are timed in respect to those gates and placed with them, not at the barrier itself.

7.2.2 Additional Elements

High speed rail is new to this country. These crossing treatments for HSR are also new. Information systems at the crossing will be one critical part of educating motorists and helping them use the crossings easily, comfortably, and safely. Special circumstances may also call for particular design elements for control.

7.2.2.1 TMC Contact Signs

Every remaining at-grade crossing should be clearly identified with a unique crossing number. With that identifier should be instructions and the number to call the TMC to report any problems. At crossings requiring phone clearance, instructions and the TMC automatic phone system number should be posted.

7.2.2.2 Variable Message Sign

Variable message signs have proven useful in reducing anxiety about long waits. They are also used to direct traffic to alternate routes and to advise people in emergency situations. All of these applications potentially come into play at HSR crossings. A default crossing alert will normally be displayed. At activation, the sign can direct all to stay clear of tracks and advise motorists of when the train will pass. The sign could rotate through a set of messages: when the train will arrive, "Train Cannot Stop Before Crossing!" and direction to the nearest grade-separated crossing. The VMS would always be available to the TMC personnel, for instance to display "Help is on the way."

7.2.2.3 Audible Message

At pedestrian crossings, this might be a speaker. For motorists a leaky coax could transmit a signal to car radios at a frequency indicated on informational signs at the crossing. The information would be essentially the same as that given by a variable message sign.

7.2.2.4 Gates/Barriers as Fence Elements

Particular fields may be fenced to contain livestock; sections of the HSR corridor may be fenced to reduce trespassing. Where the line is fenced, crossings must not present gaps in the protection. Cattle guards before the crossing may serve in some instances. Gates and barriers for private crossings are available in designs appropriate for containing livestock and/or excluding pedestrians. Public crossings, normally left open, present a different problem. One solution would be to use a gate/barrier which swings horizontally to block either the track or the road. This has been a standard crossing gate type in other countries. Normally the gate would cross the tracks from one fenceline to the other, parallel to the roadway. At activation, this part of the system would swing round, probably with the end rolling on a quarter circle track, to block the road and allow passage of the train. Barriers of this design are in use on the approaches to movable bridges.

7.2.2.5 Pedestrian Gates

Pedestrian treatments lie beyond the scope of this report. Pedestrians must be considered at in-town street railroad crossings as well as at specifically pedestrian crossings. The requirements of the ADA for railroad crossings are not clear. Creating an at-grade crossing that can safely accommodate wheelchair cross traffic and the dynamic envelope of higher speed train traffic may be difficult or impossible—wheelchairs need narrow gaps by the rails, but train wheels' flanges do not stay tight up against the rail under the severe dynamic loadings of high speed operation. Yet pedestrians, walking or in a wheelchair, regularly ignore over and underpasses provided for them. The perceived safety value of the grade separation doesn't balance the perceived effort of going up and over. Short of grade separated pedestrian crossings, some form of warning gate blocking a sidewalk may be called for. In areas where the line is fully fenced an equivalent fence gate may be needed. This area needs more research.

8. PRELIMINARY BENEFIT/COST INFORMATION

A full benefit/cost ratio (BCR) analysis for any element of a transportation system must necessarily be quite complex. And, at best, cost/benefit analyses can only make explicit the assumptions and values which would lead to particular decisions. An analysis of the multitude of scenarios which flow from the implementation of the technologies suggested above is beyond the scope of this report. The information presented in this section, therefore, is intended only to give a feeling for the scale and for the key factors.

8.1 Benefit/Cost Ratio Limitations

The core of a BCR analysis for crossing improvements contains terms for the capital and operations costs of improvements balanced against anticipated reductions in deaths, injuries, and property damage. Changes in delay, costs of disrupted operations, and social disruptions are also important, though difficult to measure or predict. BCRs often present difficulties:

- future costs and the future value of money must be guessed at;
- loss of life and limb can be assigned a great range of values—at least an order of magnitude;
- the public response to low probability-high risk events, such as train accidents, is different from the response to more common, lesser risks presenting equal total exposure.

A detailed BCR analysis for high speed rail in Oregon faces additional difficulties:

- models for crossing accident prediction incorporate terms for accident history. Such terms depend on conditions being fairly stable through the accident history period and into the future. We cannot justify such an assumption for the Willamette Valley, which is undergoing tremendous population growth;

- on the SP mainline being considered for higher speed operations, almost all public crossings already have gates and lights—accidents are rare and so very few data are available to assess severity;

- we do not have the needed data to use prediction formulas on private crossings.

8.2 Accident frequency, severity, and costs

Research done for VOLPE presents estimates of accidents and the potential reductions based on crossing improvements (Ullman & Bing 1995). This analysis is based on data from mixed freight and passenger rail lines from the FRA Railroad Accident/Incident Reporting System (RAIRS) for the years 1986 to mid-1993. For a hypothetical 500 km (310 mile) corridor with 24 one-way trips/day on weekdays and 20 one-way trips/day on weekends and holidays they project 13.0 grade crossing collisions per year resulting in 5.0 injuries and 1.3 fatalities.

Ullman and Bing point to the lack of data available to ascertain the increased severity of accidents with increased train speed. As a very rough starting point, they suggest that severity can be thought of as proportional to the energy dissipated in an accident—roughly proportional to the square of the speed. Using this approach, they estimate reductions in the number of accidents which would be required at various speeds to maintain the same overall casualties (Table 8.1).

Considering offsetting factors, they suggest "overall, a reduction in accident frequency of the order of 30-40% may be desirable for speeds of 175 kph, and 50-70% for speeds exceeding 200 kph." (Ullman & Bing 1995 pg.24). One difficulty with assigning increased severity in proportion to the square of the speed is that it

Table 8.1 — Accident reductions required for higher speeds.

Speed, kph (mph)	Reduction in accidents
145 (90)	23%
175 (110)	48%
200 (125)	60%
240 (150)	72%

may not adequately reflect the sharp increase in severity when train speeds are high enough to expect derailment following from a grade crossing collision.

The FRA has standard values which it applies to compare the benefits of avoiding casualties among different regulatory scenarios. "$ 20,000 is the value used by FRA to represent the amount society would be willing to pay to avoid an average injury to a railroad employee. FRA uses $2.6 million as the amount society is willing to pay to avoid a fatality to a railroad employee." (*Railroad Communications* 1994 pg.58). One way of thinking about these numbers is that every fatality prevented pays for the cost of a grade separation—if one uses these values for the BCR.

Cost figures based on casualties alone do not include property damage, loss of lading, wreck clearance, or environmental cleanup. In lower speed collisions, involving the destruction of a motor vehicle with relatively minor damage to train equipment, lading, and operations, casualty costs likely would be most important, and be limited to the occupants of the motor vehicle. At higher speeds, derailment becomes much more likely with a resulting sharp increase in casualty, property, and incidental damages.

8.3 Benefit, in reduced casualties, of reduced accidents

Taking the freight/passenger corridor accident figures from Ullman and Bing and the casualty costs used by the FRA, one can calculate a current acceptable accident cost per km per year of $ 6,960:

[(5.0 injuries/yr * $20,000) + (1.3 fatalities/yr * $2.6m)] / 500 km = $ 6,960 /km/yr

Over a period of 20 years, this yields acceptable accident costs of just under $140,000 per km. This figure is based only on the costs of casualties from grade crossing accidents. Calculating acceptable costs per length of track is also only one approach; an accident cost per passenger per kilometer could also be used.

To maintain a positive BCR, spending for crossing safety should be in proportion to the resulting reduction in accident severity. Using the figure above as a starting place, an accident reduction of 30% would have a benefit of—would justify expending—about $42,000 per km for 20 yr improvements. An accident reduction of 50% would justify $70,000.

In a typical rural section of the Willamette Valley 1010 HSR corridor in Oregon, where trains would be expected to run at their highest speeds, crossings average one per 1.5 km. Continuing with the numbers above, accident reductions of 50% would justify spending an average of $105,000 per crossing, again based only on costs of casualties and with the assumptions given above.

Detailed crossing information is available for the public, low volume crossings on the Oregon HSR corridor. Oregon's accident prediction formula yields an average predicted accident rate of 0.20 per five years for these crossings. Assuming the ratio of injuries to fatalities and the costs to society given above, the average accident cost comes to about $275,000 if all accidents resulted in only one injury or fatality. Over 20 years, the 0.8 predicted accidents per crossing would represent $220,000 per crossing. An accident reduction of 50% would justify spending of $110,000 per crossing—well in line with the numbers above.

8.4 Costs and accident reduction potential of treatments

Costs for various crossing treatments are among many economic considerations presented in the TRB Special Report on high speed surface transportation options (*In Pursuit* 1991). The following figures are used (derived from tables pgs 143ff):

- Full Grade Separation $ 1,903,200
- Crossing Elimination $ 52,000
- Four Quadrant Warning Gates $ 81,120

Beyond warning systems, vehicle arresting barriers are needed to protect trains operating at higher speeds. Costs for "rigid" barrier systems range from manually operated crash-rated cable beam gates—about $15,000 plus installation for two 25 foot gates—up to automatic very heavy duty barricades at about $70-$100,000 to block a two lane road in both directions. A ballpark figure given for a dragnet system is about $75, 000, presumably per side (Mobile Barrier 1994). These costs do not include the need for a conventional warning system prior to the arresting barrier.

Stalled vehicle detectors are estimated to reduce accidents by 19 percent, while four quadrant gates would reduce accidents by 57 percent (Ullman & Bing 1995).

Crossing elimination and grade separation are each ways of virtually eliminating crossing accidents. Crossing elimination is not inexpensive, but it more than meets that cost with the benefit of accident reduction. The same cannot be said of full grade separations. Additional grade separations along a corridor must be partially justified by eliminating delay costs of at-grade crossings.

Accident reductions attributable to traveler information systems, in-cab crossing video, vehicle arresting barriers, and combinations of these and other technologies can only be speculated on with present experience. Nonetheless, it appears likely that the costs and benefits of ITS technologies to improve crossing safety will be of the same order of magnitude.

9. CONCLUSIONS AND RECOMMENDATIONS

Many jurisdictions favor an incremental approach to high speed rail. Dramatic improvements in highway-railroad crossing safety are required to operate trains in the incremental speed range—130-200 kph—while maintaining current overall safety of operations. Current and emerging ITS technologies can provide these needed safety improvements. While this research has been driven by the needs of high speed rail, crossing safety is already a major concern for conventional rail operations. The systems identified for improving HSR low volume crossing safety have the potential of much wider application.

The potential of some technologies may be almost immediately realized with presently available equipment. Other systems are in development or depend for greater effect on large scale capital improvements and coordination of approach among railroads. As examples: four quadrant gates with intrusion detection to keep open exit gates until all vehicles are clear exist in Sweden; video systems to monitor crossings are used in Britain; combining video monitoring and video image processing intrusion detection for crossings is about in the proving stage in this country. Coded track circuits currently can provide multiple levels of response to conditions ahead on the track, in principle including crossing status. Crossing control based on more sophisticated, GPS based train information and control is approaching prototype testing. Tying together train and crossing status with an in-vehicle GPS/GIS traveler information system will depend on such TISs first finding greater development and wider general use.

Here in Oregon, further research is now needed to gather more complete data on private crossings and to develop and conduct field tests and pilot programs for HSR-low volume road crossing improvements. Potential sites for field tests need to be identified. Beyond isolated field tests, the low frequency of crossing incidents and the importance of driver expectancy to behavior may justify more extensive, multi-crossing pilot programs along significant lengths of a corridor.

Parallel to this research, four other areas of needed high speed rail research bear on highway-rail crossing design. A specific crossing issue is maintenance. Low volume gravel-surfaced roads present particular concerns for the integrity and function of both the track and crossing safety devices. Another issue with potential to strongly influence gate and/or barrier design is the question of fencing. If the railway must be fully fenced off, crossings controls must also function as part of the fencing system. Intrusions by pedestrians, by livestock or pets, and by wildlife all present their own sets of problems. The whole question of ADA appropriate pedestrian treatments needs study. Finally, study of likely derailment behavior of high speed trainsets may give more precise guidance to the need for higher type treatments at grade crossings.

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APPENDIX

GLOSSARY OF TRANSPORTATION ACRONYMS

AAR	Association of American Railroads
ABS	Automatic Block Signals
ACS	Automatic Cab Signals
AHS	Automated Horn System
ARES	Advanced Railroad Electronics System
ASC	Automatic Speed Control
ATC	Automatic Train Control
ATCS	Advanced Train Control System
ATS	Automatic Train Stop
AVL	Automatic Vehicle Location
CACS	Comprehensive Automobile Control System
CATC	Continuous Automatic Train Control
CCTV	Closed-Circuit Television
CTC	Centralized Traffic Control
CWT	Constant Warning Time
DB	Deutsche Bahn (German National Railway)
DOT	Department of Transportation
EBO	Eisenbahn Bau- und Betriebsordnung (German Railroad regulations)
EVA	Estación de Visión Artificial (artificial vision station)
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
FSB	Full Service Brake
FTA	Federal Transit Administration

GIS	Geographic Information System
GPS	Global Positioning System
hsr	High Speed Rail
ICE	Intercity-Express
ITS	Intelligent Transportation System
MAS	Maximum Authorized Speed
MDT	Mobile Data Terminal
MUTCD	*Manual on Uniform Traffic Control Devices*
NEC	Northeast Corridor
NHTSA	National Highway and Transportation Safety Administration
NUTCD	National Committee on Uniform Traffic Control Devices
PTC	Positive Train Control
PTS	Positive Train Separation
RAC	Railway Association of Canada
RAIRS	Railroad Accident/Incident Reporting System
RF	Radio Frequency
SAPRR	Société de Autoroute Paris-Rhin-Rhône
TCS	Traffic Control System
TIS	Traveler Information System
USDOT	United States Department of Transportation
VIP	Video Image Processing
VNTSC	John A Volpe National Transportation Systems Center
VPAS	Vehicle Proximity Alerting System
WADS	Wide Area Detection Systems