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16. Abstract

The design of at-grade intersections near highway-railroad grade crossings is challenging because of the interaction between the two geometric features. Their designs can have a critical effect on safety and operation at both features. This report provides background information regarding a number of issues related to the following specific areas: traffic control devices, signal interconnection, channelization, high-profile or "hump" crossings, and illumination.

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Some of the traffic control device drawings are from R.C. Moeur's *Manual of Traffic Signs*, (http://members.aol.com/rcmoeur/). The drawings are reproduced from the website by permission. The authors thank Mr. Moeur for the use of the drawings.

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CHAPTER 1
INTRODUCTION

The large number of crashes at grade crossings in Texas is a continuing concern of the Texas Department of Transportation. At-grade intersections near highway-railroad grade crossings may contribute to driver confusion and traffic safety concerns. Current TxDOT guidelines address at-grade intersection design but do not address special considerations for designing at-grade intersections near highway-railroad grade crossings. Such guidance has the potential of improving grade cross ing safety and thus, benefiting TxDOT and the driving public.

This research report provides background information regarding a number of items that should be considered when designing at-grade intersections near highway-railroad grade crossings:

- effects of variations in the distance between intersections and grade crossings;
- recommended regulatory, warning, and guide signs;
- effect of varying spacing between the intersection and grade crossing on traffic operations;
- design of gradelines to avoid problems due to high-profile or "hump" crossings;
- effect of illumination; and
- effect of intersection signalization.

CHAPTER 2

SURVEY OF TxDOT DESIGN PRACTICES AND PROBLEMS

Researchers conducted a survey of TxDOT district personnel to assess past and current problems and/or concerns and special design considerations that have been used with regard to the design of highway-railroad grade crossings near highway intersections.

Questions were developed regarding (but not limited to) the following areas and issues:

- design vehicles,
- vehicle storage distance,
- intersection turn/by-pass lanes,
- signage and pavement markings, and
- illumination.

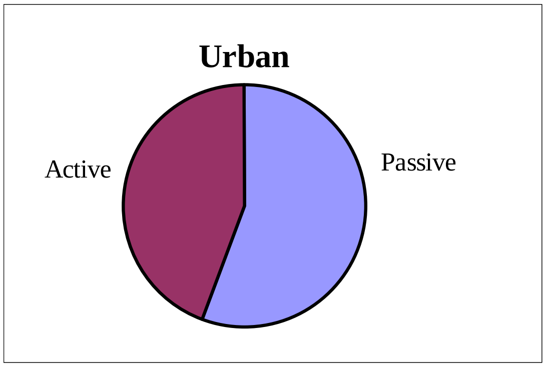
The objective of the survey was to gain more information concerning geometric design guidelines as they relate to intersections near at-grade highway-railroad crossings.

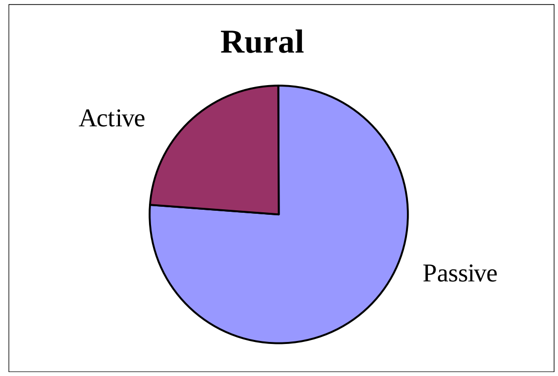
For background and documentation purposes, the appendix contains a copy of the survey. A total of 11 survey responses were returned, representing 11 of TxDOT's 25 districts. The majority of the survey respondents were design engineers, although two traffic engineers also responded to the survey.

Summary of Survey Results

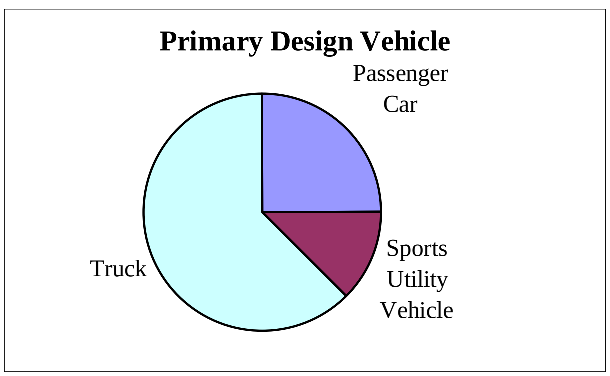
The following questions pertain to general design considerations for at-grade roadway intersections near railroad grade crossings.

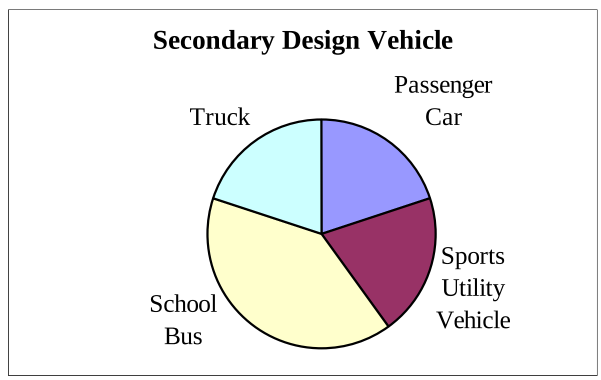
1a. Please estimate the percentage of grade crossings in your district within 200 ft of an at-grade intersection.



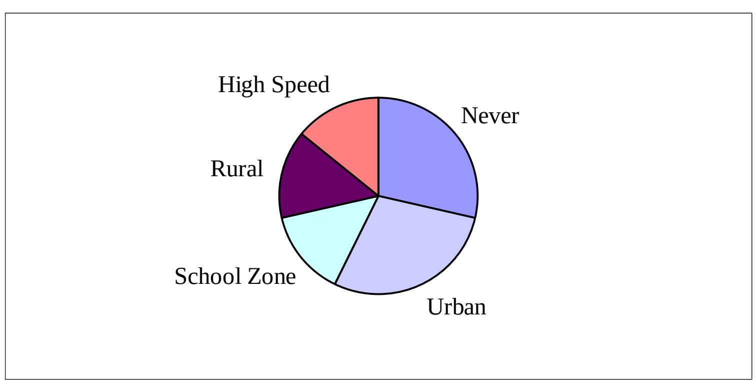


1b. What design vehicle do you use for designing at-grade intersections near railroad grade crossings?

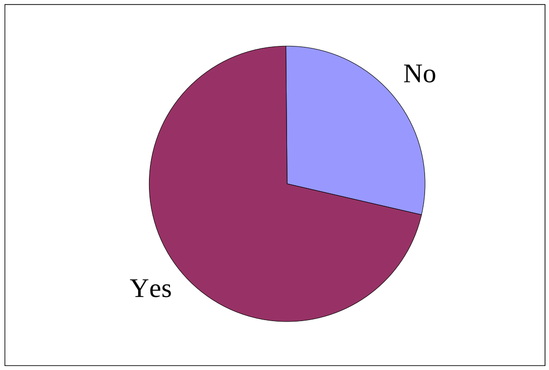




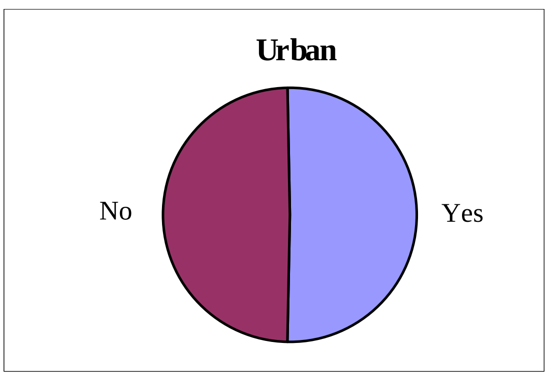
1c. When do you consider the use of a secondary design vehicle?

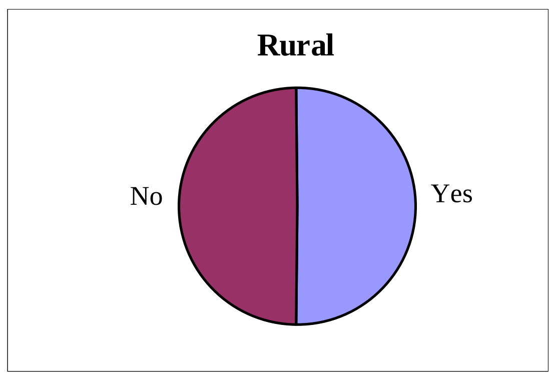


1d. For newly designed or redesigned intersections, do you give special consideration to the approach grades to the railroad grade crossing?



1e. When widening roadways toward parallel railroad tracks, have you had a problem with the creation of “hump” crossings on intersecting roadways? (A hump crossing is a high profile crossing where the railroad tracks may potentially impact long truck trailers with low ground clearances.)





1f. If you have had problems due to the presence of “hump” crossings, please describe the problem, what actions were taken, and how the crossings were improved (if applicable).

Three respondents reported problems.

1g. Do you illuminate the railroad grade crossing if the nearby at-grade roadway intersection is illuminated?

No reported illumination, rural or urban.

1h. Do you illuminate the nearby at-grade roadway intersection if the railroad grade crossing is illuminated?

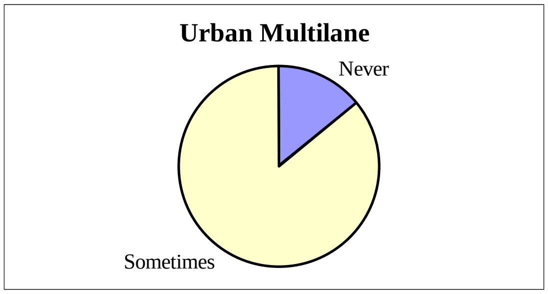
Generally never, although two reported “sometimes.”

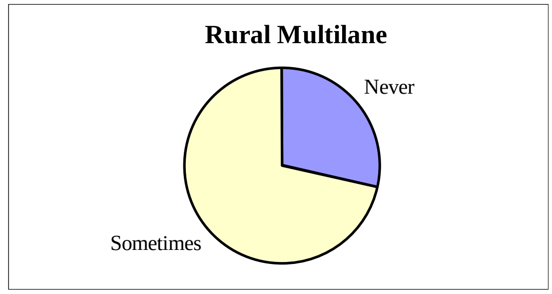
1i. Do you illuminate railroad grade crossings if there is no nearby roadway intersection?

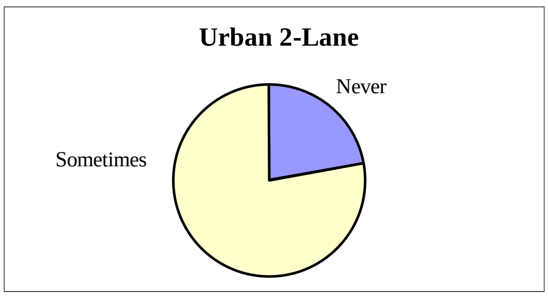
None reported.

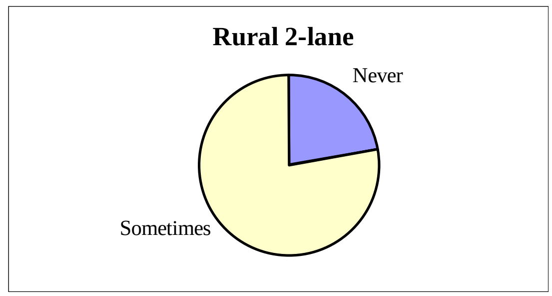
2. The following questions pertain to auxiliary lanes on the roadway that ***parallels the railroad tracks*** (an operations goal sometimes is to not block through traffic on this parallel roadway).

2a. Do you provide turn lanes for traffic turning right toward the railroad tracks?

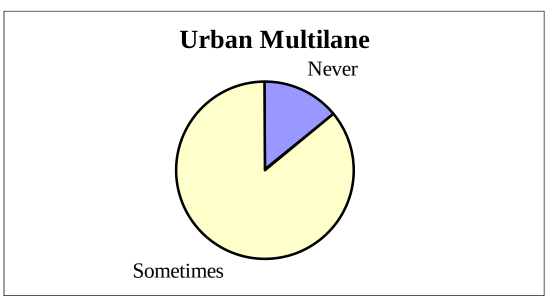


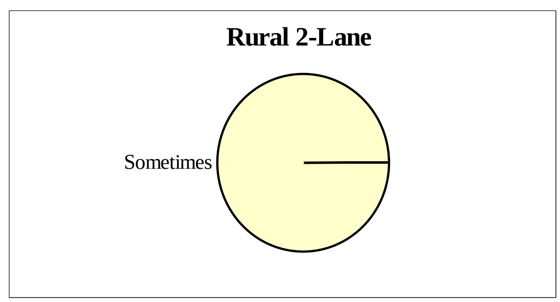


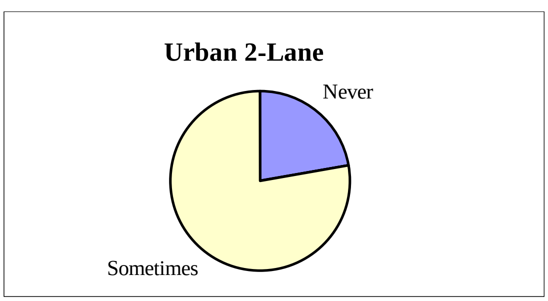


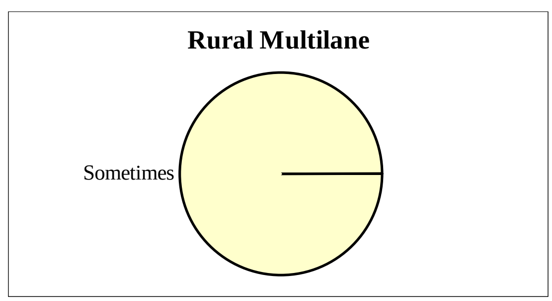


2b. Do you provide turn lanes for traffic turning left toward the railroad tracks?

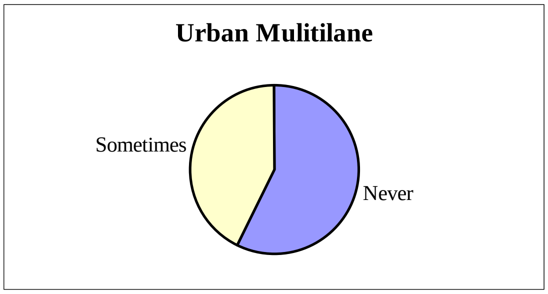


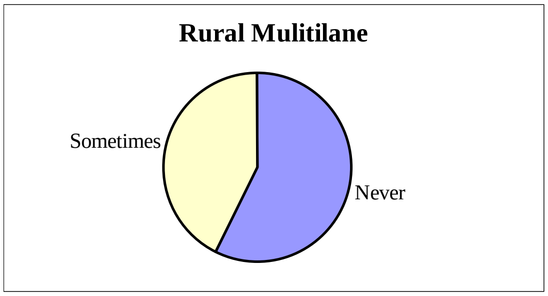


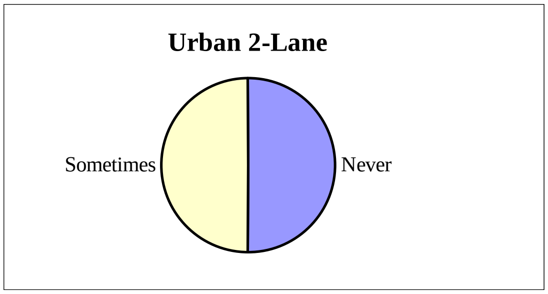


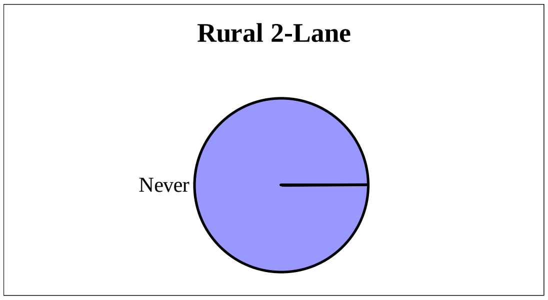


2c. Does the presence of the nearby grade crossing affect the lane layout or provision of auxiliary lanes on the roadway that is parallel to the railroad tracks in some other manner?



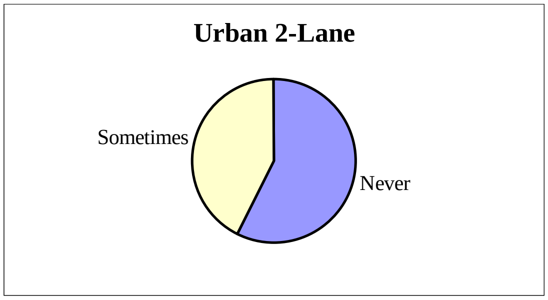


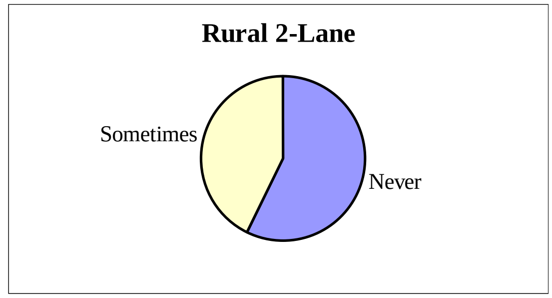


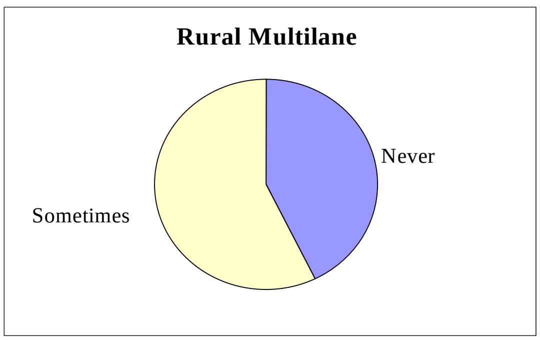


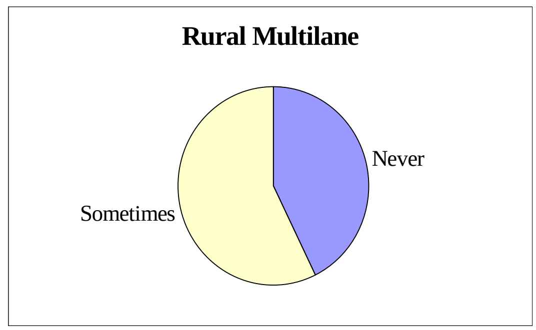
3. The following questions pertain to auxiliary lanes on the roadway that ***intersects the railroad tracks***.

3a. Does the presence of the railroad grade crossing affect the layout of right-turn lanes?

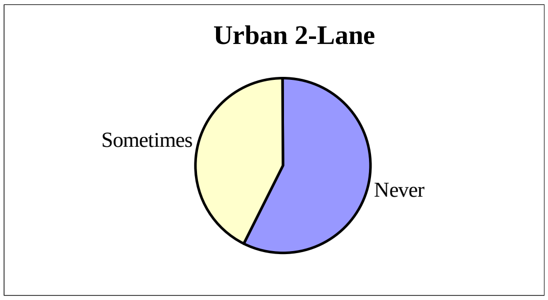


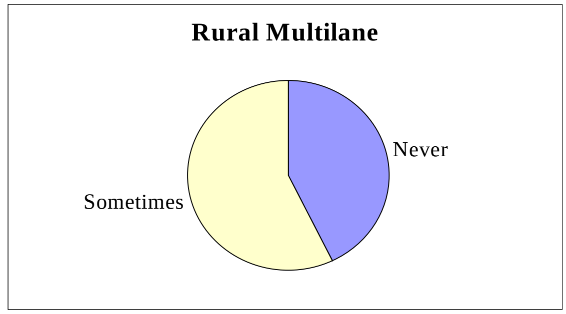


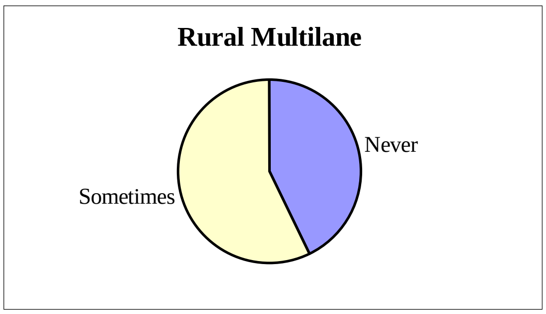


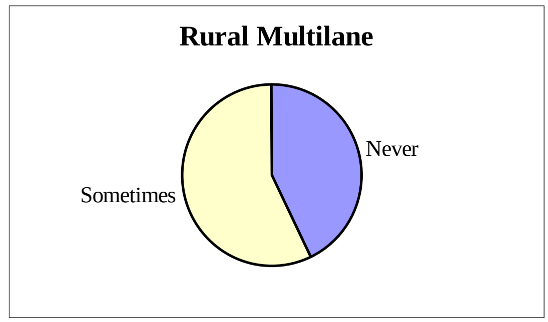


3b. Does the presence of the railroad grade crossing affect the layout of left-turn lanes?

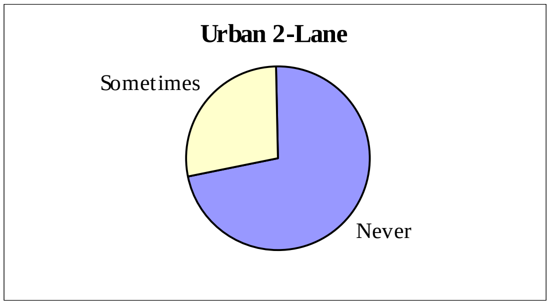


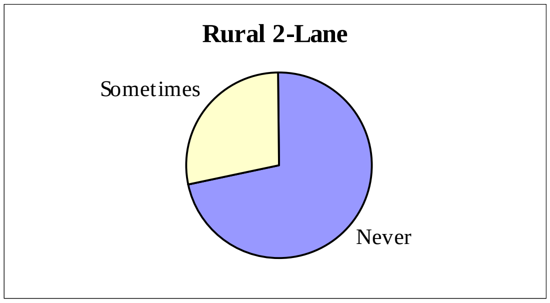


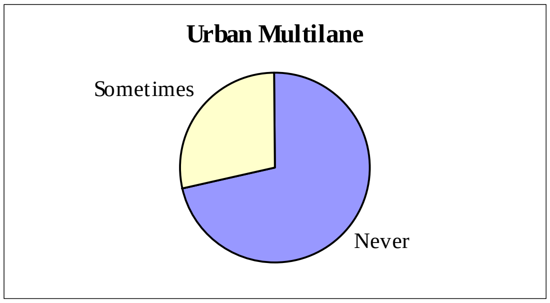


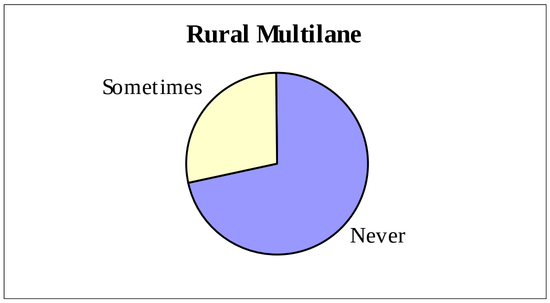


3c. Does the presence of the nearby grade crossing affect the lane layout or provision of auxiliary lanes on the roadway that intersects the railroad tracks in some other manner?









4a. Do you provide additional signs or markings on the roadway ***parallel to the railroad tracks*** <u>because</u> of the closeness of the grade crossing to the at-grade intersection?

Sign or Marking	*Always*	*Never*	*Sometimes Provided*
RR advance warning (highway parallel to railroad) (W10-2, -3, or -4)	4	0	1
No right turn (R3-1a)	0	6	0
No left turn (R3-2a)	0	6	0
Stop here on red (R10-6)	1	6	0
Do not stop on tracks (R8-8)	0	0	0
Other:			

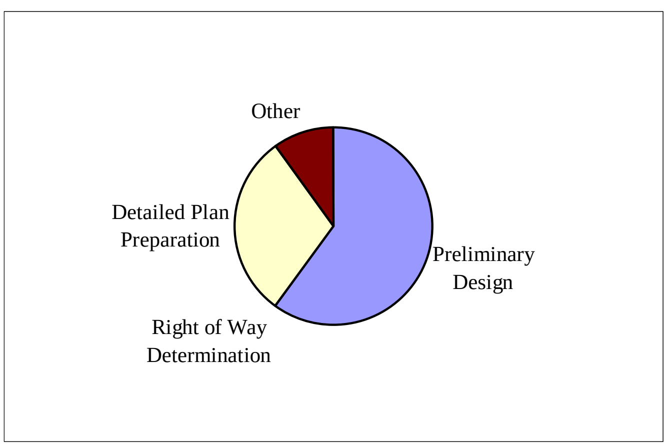
4b. Do you provide additional signs or markings on the roadway ***intersecting to the railroad tracks*** because of the closeness of the grade crossing to the at-grade intersection?

Sign or Marking	*Always*	*Never*	*Sometimes Provided*
No right turn (R3-1a)	2	2	0
No left turn (R3-2a)	1	2	1
Stop here on red (R10-6)	2	5	2
Do not stop on tracks (R8-8)	4	2	3
Stop ahead (W3-1a)	2	4	0
Signal ahead (W3-3)	2	3	0
Other:			

5. Are there locations where you prohibit vehicles stopping between the grade crossing and the parallel roadway?

One reported use when clearance was less than 20 ft, using "Do not stop on tracks" (R8-8).

6. Some safety devices placed at railroad grade crossings have limitations that require modification to allow their installation at certain locations (e.g., limits on gate length and configuration may require that islands be constructed, etc.). When in the design process are these limitations considered?



7. Could you identify some potential study sites in your district (i.e., railroad grade crossings with nearby at-grade roadway intersections)?

A number of sites were suggested, generally two per survey returned. Some consisted of corridors, although others were specific crossings.

8. What guidelines or procedures do you see when designing at-grade intersections near grade crossings? What additional guidance do you feel is needed for the design of at-grade intersections near railroad grade crossings?

The design manual and guidelines produced by the American Association of State Highway and Transportation Officials (AASHTO) were generally cited. Respondents gave consideration to approach grades, special signage, illumination, and traffic signal coordination. Additional guidance to the motorist was cited as desirable to aid the accuracy of the driver's perception of the speed of the approaching train.

Conclusions

Researchers judged a number of issues to be significant regarding the design of at-grade highway intersections and highway-railroad grade crossings based on the survey results:

- A number of different design vehicles are used in the districts.
- Hump crossings are a common problem in both urban and rural locations that are frequently not treated.
- The illumination of highway-railroad grade crossings is generally not attempted.
- The provision of and design of turn lanes are frequently affected by the presence of the highway-railroad grade crossing.

The issues raised in the survey demonstrate the presence of a significant number of potential areas of concern. Combined with information and findings contained in the literature, these issues indicate a need for guidance regarding the design of highway-railroad grade crossings near highway intersections.

CHAPTER 3
TRAFFIC CONTROL DEVICES

Intersections near highway-railroad grade crossings involve multiple types of traffic: vehicles, trains, and pedestrians. These intersections require special traffic control devices to properly coordinate the movements of these various types of traffic. There are several levels of traffic control at highway-railroad grade crossings, divided primarily into passive and active control devices. The most basic of these devices, passive devices, provide static messages of warning, guidance, and perhaps action required by the driver. Among these passive devices are signs and pavement markings. For more advanced traffic control, active control devices are necessary; these devices give warning of the approach or presence of a train and are activated by the passage of a train over a detection circuit in the track. Active control devices are supplemented by the same signs and markings used in passive control. Currently, there are a number of standards in place for the design and installation of these devices, and research is being performed to find new and more efficient uses for these devices.

Current Standards—2000 MUTCD and Others

The Texas *Manual on Uniform Traffic Control Devices* (MUTCD) is what governs design practices in Texas; the most current version of the Texas MUTCD should be consulted for specific information pertinent to Texas. However, the federal version of the MUTCD provides the majority of national standards and guidance on a variety of traffic control conditions, one of which is intersections near highway-railroad grade crossings. In the Millennium Edition (2000 Edition) of the MUTCD, Part VIII contains the vast majority of information on the subject and is divided into four major sections: General, Signs and Markings, Illumination, and Flashing-Light Signals and Gates. Other references to relevant traffic control devices are found in Sections 2A and 5F. The following sections correspond to the sections in Part VIII and reference material in the 2000 MUTCD (*1*), as well as related material from other sources.

General

Section 2A of the 2000 MUTCD contains general guidelines and standards for the use of all signs. It states that "the functions of signs are to provide regulations, warnings, and information for road users." It further states that "the use of signs should be based on engineering judgment. Results from traffic engineering studies of physical and traffic factors should indicate the locations where signs are deemed necessary."

Section 8A.1 provides an introduction to traffic control at highway-railroad grade crossings. It states that "traffic control for rail roadway intersections include all signs, signals, markings, illumination, and other warning devices and their supports along roadways approaching and at railroad crossings at grade. The function of this traffic control is to permit safe and efficient operation of both rail and roadway traffic at grade crossings." The 2000 MUTCD recognizes that any crossing of a public road and a railroad is situated on a right-of-way available for the joint use of both roadway and railroad traffic. This joint occupancy requires joint responsibility in the traffic control function between the public agency and the railroad in order to consider the safety and integrity of operations by both roadway and railroad users.

Sections 8A.2 and 3 describe the use of standard devices and uniform provisions. It advises that no single standard system of active traffic control devices is universally applicable for all roadway-rail intersections. The appropriate traffic control system should be determined by an engineering study. A standard is set forth that, prior to installation of a new or modified traffic control system, approval shall be obtained from the public agency with the jurisdictional and/or statutory authority, and the railroad should be notified. All signs used in railroad intersection traffic control systems shall be retroreflectorized as described in Section 2A.18 to show the same shape and color to an approaching motorist during both day and night. Where the distance between tracks, measured along the roadway, exceeds 30 m (100 ft), additional signs or other appropriate traffic control devices should be used.

Signs and Markings

The 2000 MUTCD provides specifications for the use of certain specific signs and markings that are used at or near highway -railroad grade crossings. Section 8B.1 states that the purpose of passive traffic control systems, consisting of signs and pavement markings, is to identify and direct attention to the location of a rail-roadway interaction and advise roadway users and pedestrians to take appropriate action.

The first sign discussed in the 2000 MUTCD is the RAILROAD CROSSING (Crossbuck) sign (R15-1, -2), which is discussed in Sections 5F.2 and 8B.2. The crossbuck sign (R15-1) shall be used at all highway-railroad grade crossings and shall be installed on the right side of the roadway on each approach to the rail-roadway intersection. If an engineering study determines that unfavorable road geometry results in restricted sight distance on the right side of the roadway, a second crossbuck sign shall be provided for the approach, possibly placed back-to-back with the crossbuck sign facing the opposite approach. If there are two or more tracks between the signs, the number of tracks shall be indicated on a supplemental sign (R15-2), except that use of the R15-2 sign is optional at crossings with automatic gates. The crossbuck sign shall be retroreflectorized white with black lettering, mounted as shown in Figure 1. (*1*)

The RAILROAD ADVANCE WARNING signs (W10-1, -2, -3, -4) are described in Sections 5F.3 and 8B.3. A W10-1 sign shall be used on each roadway in advance of every roadway-rail intersection except: 1) on low-volume, low-speed roadways crossing minor spurs or other tracks that are infrequently used and which are flagged by train crews; and 2) in the business districts of urban areas where active roadway-rail intersection traffic control devices are in use. On divided highways and one-way roads, an additional W10-1 sign may be erected on the left side of the roadway. W10-2, -3, and -4 signs may be installed on highways that run parallel to railroads to warn motorists making a turn that they will encounter a railroad crossing soon after making the turn. Where the distance between the railroad and the parallel roadway is 30 m (100 ft) or more, a W10-1 sign should be installed in advance of the roadway-rail intersection, and the W10-2, -3, or -4 signs on the parallel roadway should not be used. Examples of the W10-1, -2, -3, and -4 signs are shown in Figure 2. (*1*)

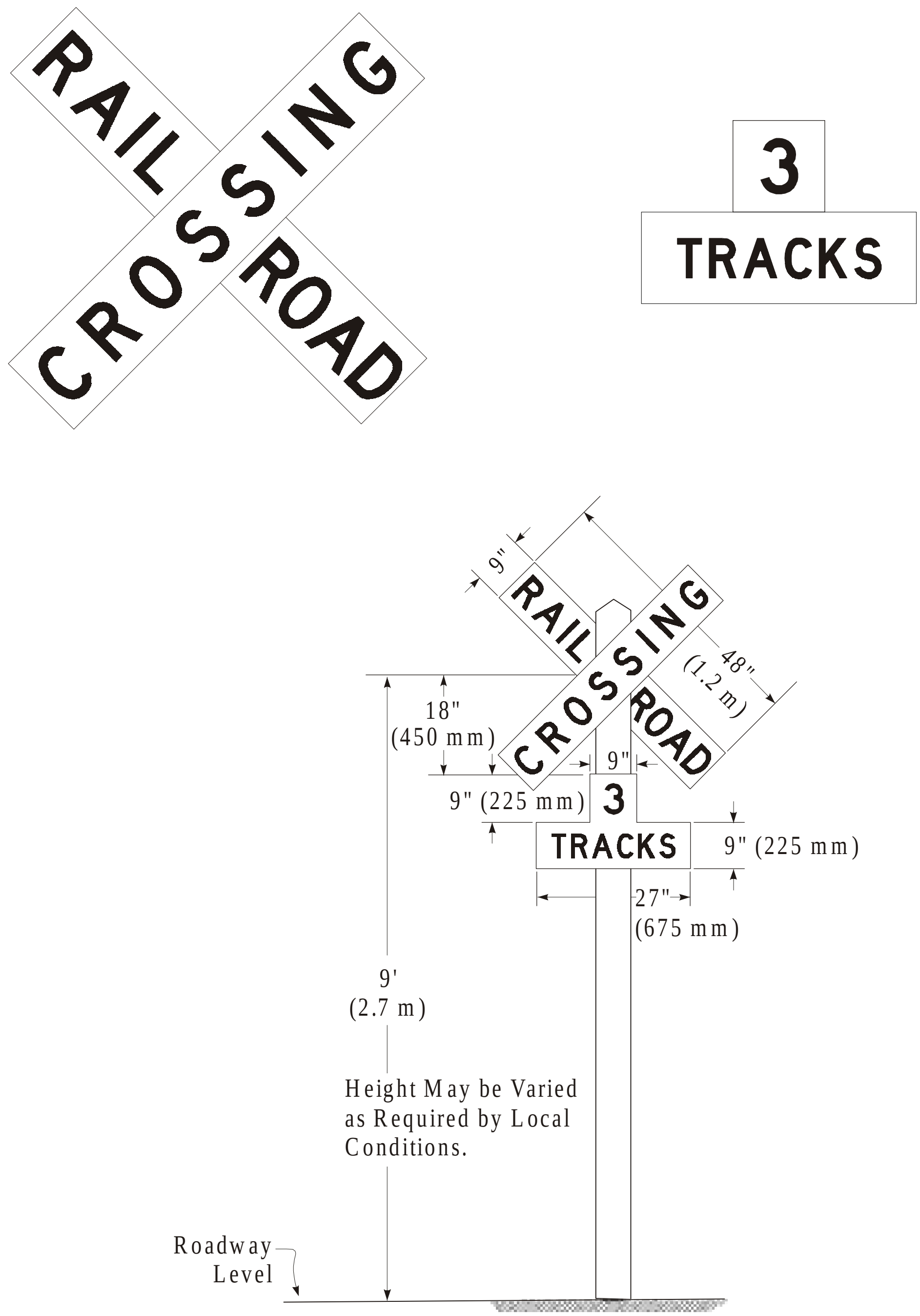


Figure 1. Railroad-Highway Crossing (Crossbuck) Sign. (*1*)

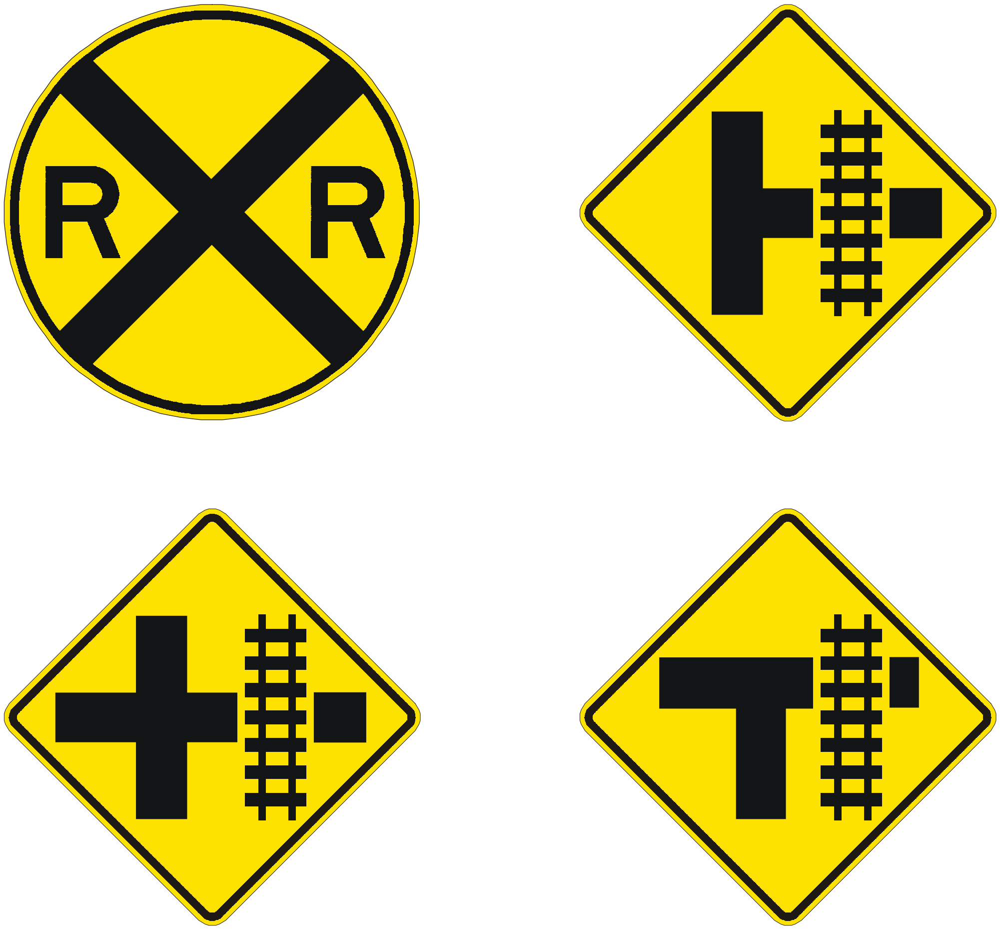


Figure 2. Railroad Advance Warning Signs. (*1*)

Supplemental signs are used to indicate crossings that meet certain requirements for exemption. EXEMPT crossing signs (R15-3, W10-1a) are described in Section 8B.4 of the 2000 MUTCD. These supplemental signs inform drivers of regulated vehicles (vehicles carrying passengers for hire, school buses carrying children, or vehicles carrying flammable or hazardous materials) that a stop is not required at certain designated grade crossings, except when a train, locomotive, or other railroad equipment is approaching or occupying the crossing, or the driver's view of the sign is blocked. When authorized by law or regulation, a supplemental sign (R15-3) bearing the word EXEMPT may be used below the crossbuck sign and track signs at the crossing. The supplemental sign (W10-1a) may be used below the RAILROAD ADVANCE WARNING sign. An example of R15-3 and W10-1a is shown in Figure 3. (*1*)

Other supplemental signs discussed in the 2000 MUTCD include the DO NOT STOP ON TRACKS sign (R8-8) and the TRACKS OUT OF SERVICE sign (R8-9), which are found in Sections 8B.6 and 8B.8, respectively. Whenever an engineering study determines that the potential for vehicles stopping on the tracks is high, an R8-8 sign should be used. Placement of R8-8 signs should be determined as part of the study. When used, the R8-8 sign should be located on the right side of the road on the near or far side of the intersection, whichever provides better visibility to approaching drivers. On divided roadways and one-way roads, a second sign may be placed on the near or far left side of the grade crossing to further improve visibility. The R8-9 sign may be used at a crossing in lieu of RAILROAD CROSSING signs (R15-1, -2) when railroad tracks have been temporarily or permanently abandoned and their use discontinued, but only until such time that the tracks are removed or paved over. When tracks are not in service, traffic control devices and gate arms shall be removed, the signal heads removed or turned from view to clearly indicate that they are not in operation, and all related signs and markings shall be removed. The R8-9 sign shall be removed when the tracks have been removed or covered, or when the intersection is returned to service. Examples of the R8-8 and R8-9 signs are given in Figures 4 and 5. (*1*)

Figure 3. EXEMPT Sign. (*1*)

Figure 4. DO NOT STOP ON TRACKS Sign. (*1*)

Figure 5. TRACKS OUT OF SERVICE Sign. (*1*)

Certain roadway intersections have geometric considerations that require restrictions on turning movements. According to Section 8B.5, at a signalized roadway intersection that is located within 60 m (200 ft) of a roadway-rail where the roadway intersection traffic control signals are preempted by the approach of a train, all existing turning movements toward the roadway -rail intersection should be prohibited during the signal preemption sequences. A blank-out or changeable message and/or appropriate traffic signal display or other similar type sign may be used to prohibit turning movements during preemption; these displays shall be visible only when the turn restriction is in effect.

STOP (R1-1) or YIELD (R1-2) signs may be used at highway -railroad grade crossings, at the discretion of the responsible state or local jurisdiction, for crossings that have two or more trains per day and are without automatic traffic control devices. Section 8B.7 describes "two or more trains" as an average of two or more trains operating over the roadway-rail intersection each day for a period of one year prior to the installation of the STOP or YIELD sign. Other crossings with passive protection may use STOP or YIELD signs after a traffic engineering study establishes the need for the signs. The study should take into consideration such factors as volume and character of accident history, as well as the need for active control devices. When a STOP or YIELD sign is installed at a grade crossing, it should be erected on a separate post at a point where the vehicle is to stop, or as near to that point as possible. For all crossings where STOP or YIELD signs are installed, the placement shall conform to the requirements of Section 2B-9; STOP AHEAD (W3-1a) or YIELD AHEAD (W3-2a) advance warning signs shall also be installed. (*1*)

The 2000 MUTCD provides standards for pavement markings in Section 8B.9. Pavement markings in advance of a roadway -rail intersection shall consist of an X, the letters RR, a no-passing marking (for two-lane roads), and certain transverse lines. Identical markings shall be placed in each approach lane on all paved approaches to intersections where signals or automatic gates are located, and at all other roadway-rail intersections where the posted or statutory speed is 60 km/h (40 mph) or greater. At minor roadway-rail intersections where the posted or statutory speed is less than 60 km/h (40 mph) or in urban areas, these markings shall not be required if an engineering study indicates that other installed devices provide suitable warning and control. The markings shall also be placed at roadway-rail intersections where engineering studies indicate significant potential for conflict between vehicles and trains. All markings shall be retroreflectorized white except for no-passing markings, which shall be retroreflectorized yellow. When pavement markings are used, a portion of the X symbol should be directly opposite the ADVANCE WARNING sign. The X symbol and letters should be elongated to allow for the low angle at which they will be viewed. (*1*)

Stop lines should be placed at a point where the vehicle driver has adequate sight distance along the track to determine whether it is safe to cross the track. Guidance in the 2000 MUTCD states that the Stop line should be a transverse line at a right angle to the traveled way and placed approximately 4.5 m (15 ft) from the nearest rail. The distance between the Stop line and the nearest rail may be reduced to a minimum of 2.4 m (8 ft) when necessary to allow for adequate sight distance. (*1*)

Whenever conditions are sufficiently abrupt to create a hang-up of long wheelbase vehicles or trailers with low ground clearance, the 2000 MUTCD states that the “Low Ground Clearance” (W10-5) warning symbol sign shall be installed in advance of the crossing. New warning symbol signs such as this may not be readily recognizable by the public and shall be accompanied by an educational plaque, which is to remain in place for at least three years after initial installation. (*1*)

Illumination

Illumination devices are supplemental to traffic control devices, but there are guidelines for their use. At highway-railroad grade crossings where a substantial number of railroad operations are conducted at night, illumination at and adjacent to the crossing may be installed to supplement other traffic control devices where an engineering study determines that better visibility of the train is needed. Section 8C-1 of the 2000 MUTCD states that “luminaries shall be so located and their light directed to not interfere with visibility of the railroad signal system and to not restrict the view of the locomotive crew.” (*1*)

Flashing-Light Signals and Gates

One of the most predominant forms of active traffic control is the use of automatic gates, which physically block the travel lanes and are used in conjunction with flashing lights. Current practice generally employs the use of two gate arms, one for each direction of traffic. Gate length varies depending on the width of the travel lanes they are to block. Gates are reflectorized and have additional red lights attached to the arm that flash alternately to increase visibility at night. (*2*)

According to the *Railroad-Highway Grade Crossing Handbook* published by FHWA, an automatic gate "serves as a barrier across the highway when a train is approaching or occupying the crossing. The gate is reflectorized with 16-inch diagonal red and white stripes. To enhance visibility during darkness, three red lights are placed on the gate arm. The light nearest to the tip burns steadily while the other two flash alternately. The gate is combined with a standard flashing light signal that provides additional warning before the arm starts to descend, while the gate arm is across the highway, and until the gate arm ascends to clearance." (*3*)

FHWA also describes the sequence of normal operation as follows: "…the flashing light signals and the lights on the gate arm in its normal upright position are activated immediately upon the detection of the approach of a train. The gate arm shall start its downward motion not less than three seconds after the signal lights start to operate, shall reach its horizontal position before the arrival of the train, and shall remain in that position as long as the train occupies the crossing. When the train clears the crossing, and no other train is approaching, the gate arm shall ascend to its upright position normally in not more than 12 seconds, following which the flashing lights and the lights on the gate arm shall cease operation." (*3*)

Regarding the fabrication of gate arms, FHWA stipulates that gates on two-way streets should cover enough of the approach to physically block the motorist from going around the gate without going into the opposing lane. On multi-lane crossings, they allow for an opening of approximately 1.8 m (6 ft) for emergency vehicles. Gates can be made from aluminum, fiberglass, or wood. Aluminum and fiberglass gates can be designed with a breakaway feature so that the gate arm separates from the mechanism when struck. In general, gate arms are not longer than 12.2 m (40 ft). When approaches are wider than 12.2 m (40 ft), it may be necessary to place gate assemblies in the median to adequately cover the approach. In these cases, FHWA says that crash cushions or other safety barriers may be desirable, but under no circumstances should signals or gate assemblies be placed in an unprotected painted median. (*3*)

Figure 6 illustrates a typical FHWA clearance plan. When no train is approaching or occupying the crossing, the gate arm is held in a vertical position; the minimum clearance from the face of the vertical curb to the nearest part of the gate arm or signal is 0.6 m (2 ft) for a distance of 5.2 m (17 ft) above the highway. Where there is no curb, a minimum horizontal clearance of 0.6 m (2 ft) from the edge of a paved or surfaced shoulder is required with a minimum clearance of 1.8 m (6 ft) from the edge of the traveled highway. Where there is no curb or shoulder, the minimum horizontal clearance from the traveled way is 1.8 m (6 ft). Where gates are located in the median, additional width may be required to provide the minimum clearances for the counterweight support.

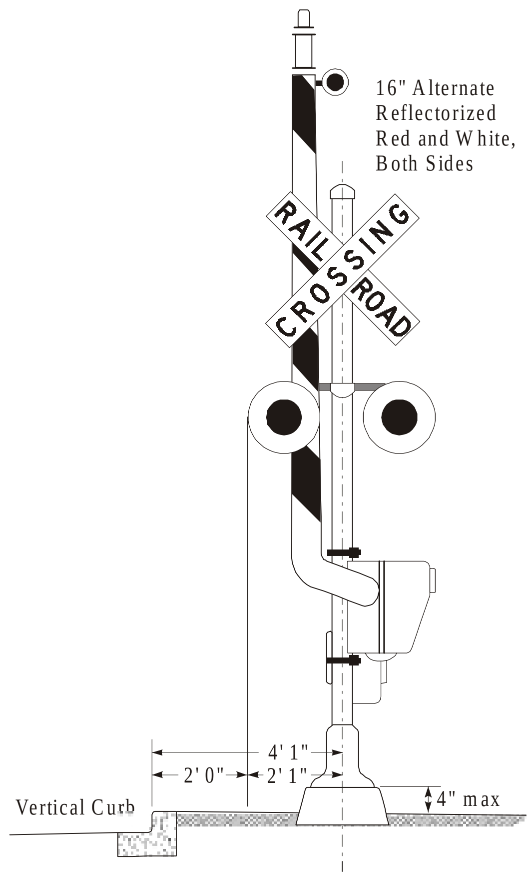


Figure 6. Typical Clearance for Flashing Light Signals with Automatic Gates. (*3*)

The lateral location of flashing light and gate assemblies must also provide adequate clearances from the track as well as space for construction of the foundations.

Figure 7 shows typical FHWA locational requirements for the foundations for flashing lights and cantilevered flashing lights with gates. While this figure shows a minimum clearance of 3.6 m (12 ft) between the center of the flashing light assembly and the center of the tracks, some railroads prefer a 4.5 m (15 ft) minimum. FHWA provides additional typical location plans for flashing light signals with and without gates for a variety of approaches, medians, and crossing angles. (*3*)

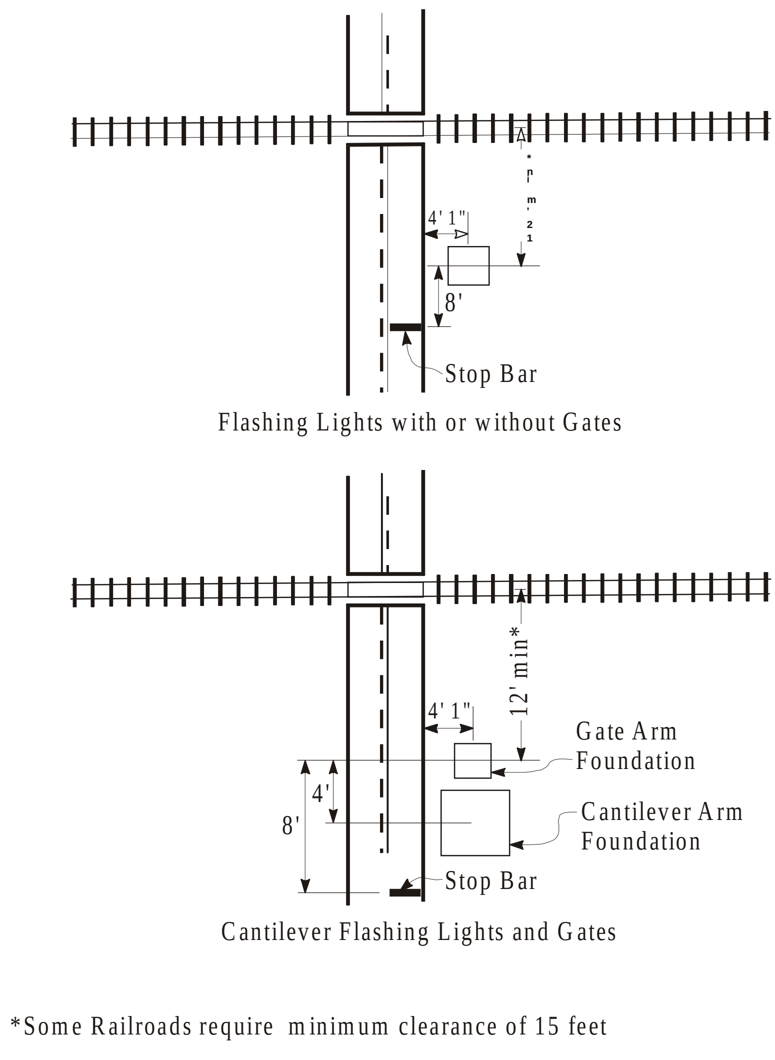


Figure 7. Typical Location of Signal Devices. (*3*)

The AASHTO Green Book makes the following comments regarding the use of automatic gates at railroad crossings: “The geometric design of railroad-highway grade crossings must be made jointly with the determination of the warning devices to be used. When only passive warning devices such as signs and pavement markings are used, the highway drivers are warned of the crossing location, but must determine whether or not there are train movements for which they should stop. On the other hand, when active warning devices such as flashing light signals or automatic gates are used, the driver is given a positive indication of the presence or the approach of a train at the crossing." (*4*)

AASHTO lists traffic control devices at grade crossings consisting primarily of signs, pavement markings, flashing light signals, and automatic gates. For standards on design, placement, installment, and operation of these devices, AASHTO refers the reader to the MUTCD. AASHTO lists several considerations for evaluating the need for devices such as automatic gates: type of highway, volume and speed of railroad and vehicular traffic, volume of pedestrian traffic, accident history, sight distance, geometrics, number of tracks at the crossing, and volume of school buses or vehicles transporting hazardous materials. AASHTO recommends that even when flashing lights and automatic gates are used, small intersection angles should be avoided. (*4*)

The 2000 MUTCD contains the same guidelines as the *Railroad-Highway Grade Crossing Handbook*, but also contains additional material that defines a standard for the design, installation, and use of automatic gates. An automatic gate is defined as a traffic control device used as an adjunct to flashing lights, shown in Figure 8.

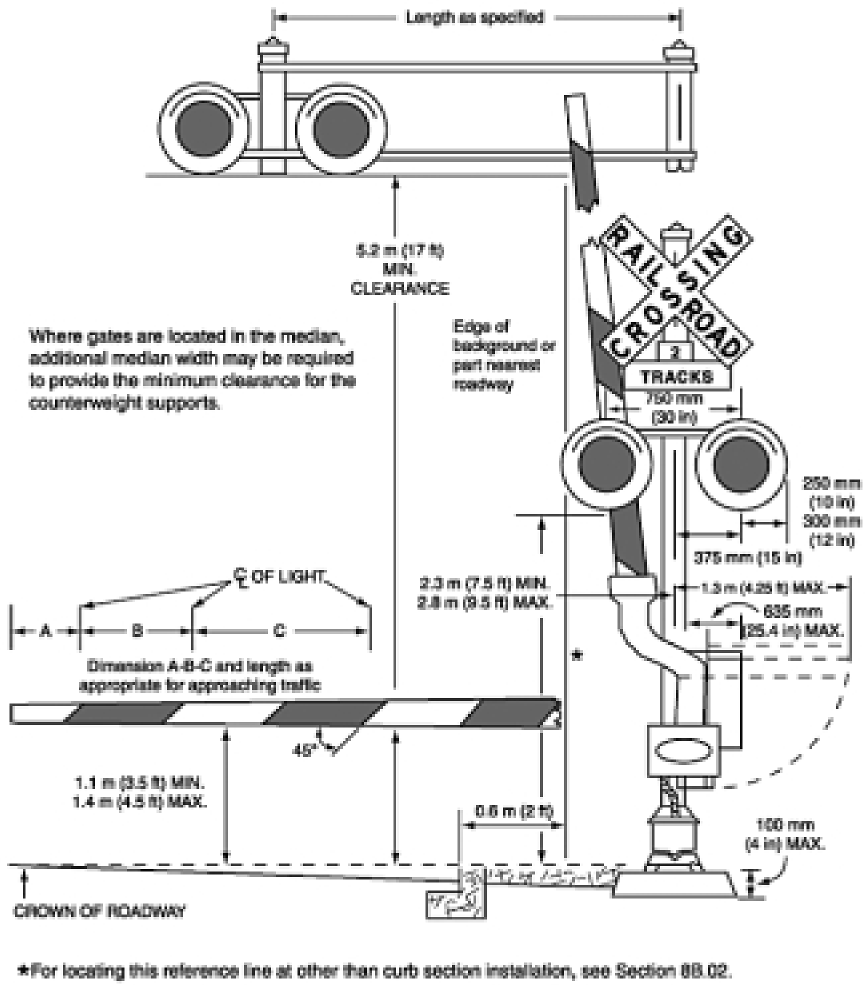


Figure 8. Composite Drawing of Active Traffic Control Devices for Roadway-Rail Intersections Showing Clearances. (*1*)

There are three main types of active traffic control systems discussed in the 2000 MUTCD: post-mounted flashing-light signals, cantilevered-arm flashing-light signals, and automatic gate assemblies. According to Section 8D.1, the meaning of flashing-light signals and gates shall be as stated in the Uniform Vehicle Code, revised 1992. Location and clearance dimensions are provided elsewhere in Part VIII of the 2000 MUTCD.

For post-mounted flashing-light signals, Section 8D.2 states that the signal assembly shall include a standard crossbuck sign, and where there is more than one track, a supplemental "number of tracks" sign, all of which indicate to vehicle operators and pedestrians the location of a highway -railroad grade crossing. Bells may be included in the assembly and may be operated in conjunction with the flashing lights to provide warning for pedestrians and bicyclists. When indicating the approach or presence of a train, the signal shall display toward approaching highway traffic two red lights in a horizontal line flashing alternately. At crossings with roadway traffic in both directions, back-to-back pairs of lights shall be placed on each side of the tracks. On multi-lane one-way streets and divided roadways, signals shall be placed on the approach side of the crossing on both sides or above the roadway, and may be equipped with back lights. The 2000 MUTCD also gives standards for illumination, flashing rates, power sources, and placement. (*1*)

Cantilevered flashing-light signals may be used where needed for additional emphasis or for better visibility to approaching traffic, particularly on multi-lane approaches. In addition to the lights on the cantilever arm, lights may be placed on the supporting post. When one pair of cantilever flashing lights would be visible to drivers in all approaching lanes, except the right lane which has a view of post-mounted signals, other flashing lights may not be required on the cantilever arm. The need for additional lights may be determined by an engineering study. Breakaway or frangible bases shall not be used for cantilevered signal supports. (*1*)

According to Section 8D.4 of the 2000 MUTCD, automatic gates shall consist of a drive mechanism, and gate arms in the down position shall extend across the approaching lanes of highway traffic. Gate arms shall be fully reflectorized on both sides, have 45 degree diagonal stripes alternately red and white at 40-cm (16-in) intervals measured horizontally, be no more than 11.6 m (38.1 ft) in length, have a vertical clearance between 1.0 and 1.3 m (3.3 and 4.3 ft) when activated, and shall have at least three red lights as indicated in Figure 8. When activated, the gate arm light nearest the tip shall be illuminated continuously, and the other two lights shall flash alternatively in unison with the flashing light signals. In its normal upright position, when no train is approaching or occupying the crossing, the gate arm should be either vertical or nearly so. In the design of individual installations, the 2000 MUTCD urges consideration of timing the operation of the gate arm to accommodate large and/or slow-moving vehicles. Gates should be long enough to cover the approaching roadway to block all motor vehicles from being driven around the gate without leaving their traffic lanes. (*1*) Standard practice in Texas varies slightly from the 2000 MUTCD in that new installation follows the standard of 11.6 m (38.1 ft) for maximum length; however, if an existing, longer gate arm needs replacing, it is replaced by an arm of equal length unless a formal agreement is made by TxDOT and the affected railroad company.

To serve their purpose of advising motorists and pedestrians of the approach or presence of trains, locomotives, or railroad cars at grade crossings, the devices employed in active traffic control systems shall be actuated by some form of train detection. Railroad control circuits, including those for train detection, shall be designed on the fail-safe principle, which uses closed circuits. Where the speeds of different trains on a given track vary considerably under normal operation, special devices or circuits should be installed to provide reasonably uniform notice in advance of all train movements over the crossing. Special control features should be used to eliminate the effects of station stops and switching operations within approach control circuits to prevent excessive activation of the traffic control devices while trains are stopped on or switching upon the approach track control circuits. (*1*)

Section 8D.6 discusses traffic control signals at or near highway-railroad grade crossings. It refers to Part VI of the manual for provisions relating to signal design, installation, and operation. It also states that traffic control signals shall not be used on roadways at railroad grade crossings in lieu of gates and/or flashing light signals. When a roadway-rail intersection is equipped with an active traffic control system, the normal sequence of traffic control signal indications shall be pre-empted upon approach of trains to avoid entrapment of vehicles on the crossing by conflicting aspects of the traffic control signals and the roadway-rail intersection warning signals. When a roadway-rail intersection with an active traffic control system is located within 60 m (200 ft) of an intersection or mid-block location controlled by a traffic control signal, the traffic control signal should be provided with pre-emption in accordance with Section 4D.13 of the 2000 MUTCD. Coordination with the intersection warning system should be considered for traffic control signals located more than 60 m (200 ft) from the crossing. Factors should include motor vehicle traffic volumes, approach speeds, and queue lengths. *(1)*

Contact with gate arm manufacturers indicated that current practice generally follows the MUTCD guidelines. Gate arms are made of wood, fiberglass, or a combination of fiberglass and aluminum. According to manufacturers, typical lengths of gate arms can range from 3.6 to 12.0 m (12 to 40 ft) for fiberglass arms and from 3.6 to 12.6 m (12 to 42 ft) for wooden arms. Arms are generally attached to the deployment mechanism using metal couplings or sleeves, and fastened by screws and/or bolts. "Breakaway" gate arm systems utilize fiberglass or fiberglass-aluminum arms with fasteners designed to shear away under excessive force, preventing major damage to the arm itself. Manufacturers indicated that, in addition to the national guidelines outlined above, there is also a variety of localized standards that vary from state to state and from railroad to railroad.

Preemption of Traffic Signals

Signalized intersections at or near grade crossings possess added concerns over intersections that are not near grade crossings. If traffic signals are not properly coordinated with railroad operations, severe accidents can occur. The Institute of Transportation Engineers (ITE), through the Traffic Engineering Council, developed a recommended practice for the preemption of traffic signals at or near railroad grade crossings with active warning devices. (*5*)

According to the ITE recommended practice, where a signalized highway intersection exists in close proximity to a railroad grade crossing, the railroad signal control equipment and the traffic signal control equipment should interconnect. This means normal operation of the traffic signals controlling the intersection should be preempted to operate in a special control mode when trains are approaching. A preemption sequence compatible with the railroad grade crossing active warning devices, such as gates and flashing lights, is extremely important to provide safe vehicular, pedestrian, and train movements. Such preemption serves to ensure that the actions of these separate traffic control devices complement rather than conflict with each other.

The traffic engineer designing the preemption system must understand how the traffic signal controller unit operates in response to a call for a preemption sequence. He or she must consult with railroad signal personnel to ensure that appropriate equipment is specified and that both signal installations operate properly and with full compatibility. Continuous cooperation between highway and railroad personnel is essential for a safe operation. The recommended practice identifies many elements necessary for proper preemption and provides references where feasible. Recommendations are provided in a general sense, with applications designed for local conditions. More information can be found within the committee's report. (*5*)

The recommended practice requires consideration of interconnecting traffic signals on public and private highways with active warning devices at grade crossings if the following conditions are present: highway traffic queues that have the potential for extending across a nearby rail crossing, and traffic backed up from a nearby downstream railroad grade crossing that could interfere with signalized highway intersections. A crossing equipped with a passive warning device may need to be upgraded to include active warning devices so that preemption of the traffic signal controller unit can be implemented. This improvement is particularly important when the tracks are close to the signalized intersection or when certain conditions exist, such as high-speed trains or highway approaches, tracks in highway medians, geometry such as steep grades, or the presence of special vehicles at the crossing, such as school buses or trucks carrying hazardous material.

When designing a preemption operation, many important items need to be considered. These items include distance between the tracks and signal, intersection and crossing geometry, approach speed of trains and vehicles, train frequency, vehicle flow rates, vehicle size and classification, and operation of the traffic signal controller unit.

Once preemption devices are placed in operation, the responsible parties should jointly develop an agreement to provide a level of maintenance equal to or better than that afforded to each party's own facilities. In addition, maintenance organizations must communicate on a regular basis. Inspection and maintenance of the system may be simplified by use of a monitored interconnected circuit, or by display of an indicator on the outside of the highway traffic control cabinet, which would provide visible notice that the preemption command has been received by the highway traffic signal controller assembly. (*5*)

Previous Research

There have been previous research efforts to examine new technologies and concepts for traffic control devices, both to improve safety and to reduce costs. Several specific research projects will be discussed here.

St. Amant, et al. (1977)

In 1977, the Federal Railroad Administration sponsored a project to consider potential means of cost reduction in automatic gate systems at grade crossings. The researchers examined several possibilities: swing-away gates, drive-over gates, multiple expendable gate arms, modular gate arms, folding gate arms, overhead cables, and overhead hinged arms. (*6*, *7*)

Swing-away gates (or rotating arms) are deflected up and away from vehicles that collide with them. They can be positioned so that the gate will not swing into the path of oncoming trains, and they provide a vertical clearance for vehicles to pass underneath them; this keeps the gate intact and reduces the need to replace broken gate arms. The "break-away" function occurs when a torque above the specified minimum for activation is applied to the pivot mechanism. After the vehicle has passed clear of the arm, gravity returns the arm to its normal position. Benefits of swing-away gates identified in this study include excellent ratings for strength, weight, rigidity, durability, resistance to vandalism, and safety. The authors recommend swing-away gates for further study. (*6*)

Drive-over resetting gates consist of a rigid arm support and a flexible flat arm with multiple flexible, vertically oriented springs, each one of which supports a short portion of a horizontal, 1.2 m (4 ft) highly visible, reflective arm. The flat arm is flexible enough to assume the curvature of the crown of the road when fully deployed. In the event a vehicle does not stop when this gate is deployed, the individually spring-supported sections of the reflective arm will be depressed in the direction of vehicle travel and downward as required to allow the vehicle to pass over with no destruction to either the arm or the vehicle. Drive-over gates received favorable ratings for visibility, strength, resistance to vandalism, and durability; however, they received only fair ratings for safety, installation, and cost reduction. Therefore, these gates were not recommended for further study. (6)

Multiple expendable gate arms were designed to reduce the purchase price per arm, reduce installation expenses, and reduce damage to highway vehicles. The main feature that distinguishes this design from commonly used systems is the method of attachment to the deployment mechanism and the presence of multiple deployable "back-up" arms. The arms are constructed of very lightweight materials and are of very simple design. A number of arms are mounted on the output shaft of the mechanism, and all of the back-up arms are retained between fixed guides and oriented in the clear position. Upon impact from a highway vehicle, the force against the deployed arm will become great enough to fracture the arm at the output shaft. When this occurs, a spring pushes a back-up arm into the position occupied by the previous arm and the new arm is deployed, thus maintaining the warning system at the crossing. Multiple expendable gate arms received good marks for weight, rigidity, visibility, and safety, but they were not recommended for further study because of durability, resistance to vandalism, weather, installation, and replacement costs. (6)

Modular gate arms are made up of many short elements, all of which are identical. The concept is based on assembly of each module onto a threaded rod and nylon rope. The benefit of this system would be the need to replace only the modules that are damaged in the event of a collision. However, problems with illumination, rigidity, durability, and potential costs prevented the authors from recommending modular gate arms for further development. (6)

Folding gate arms have a design in which the arm is raised and lowered by two actuating cables attached to a split mast. When in the raised position, the arm folds in half, which requires less overhead space. Folding arms also act as swing-away gates; any lateral displacement of the arm will result in the arm moving up and away and then returning to the horizontal position. The option of a protective housing mounted between the two masts adds extra protection against wind and ice. Disadvantages to this design include complexity of the design, which would probably increase costs. In addition, vulnerability to vandals is high with this design, which led the authors to not recommend this design for further study. (7)

In the overhead cable design, the gate arm is raised and lowered from a cantilevered arm by two cables driven by an electric drive motor and pulley arrangement. A tension cable is added to restrain the arm from oscillating during windy conditions. The arm, when impacted by a vehicle, will swing away and return to normal position after the vehicle has passed through. The cantilever also allows for mounting lights above the roadway to further warn motorists. A problem the researchers found with this design was the tension cable, which is easily accessible to vandals. Other potential problems were the formation of ice and difficulty with maintenance. These drawbacks resulted in a recommendation by the researchers to not pursue further investigation on this design. (*7*)

The concept of overhead hinged arms uses two cables driven by an electric drive motor and pulley arrangement or some other means to raise and lower the gate arm. When in the raised position, the gate arm will fold in under the overhead span, which will protect the lights mounted on the arm from vandalism. The vertical hinged arm supports are intended to provide rigidity to prevent the gate arm from oscillating in the wind. This design also has a swing-away feature that allows impacting vehicles to pass under the gate arm. There could be some difficulties with cost and maintenance, but the researchers recommended this design for further study. (*7*)

Heathington, et al. (1984)

The FHWA sponsored a study (*8*) to evaluate six innovative active traffic control devices at grade crossings. The six devices included two alternatives for each of three basic systems: four-quadrant gates (with and without skirts), four-quadrant flashing light signals (with and without strobes), and highway traffic signals (with one and with three white bar strobes). The evaluation involved testing the performance of each of the six devices in a simulated real-world environment to identify the three most desirable devices for subsequent field testing. Thirty-two test subjects drove an instrumented vehicle repeatedly over a private two-lane highway. On each trip down the roadway, the test driver encountered three full-scale active warning devices, any one of which may or may not have been actuated as the vehicle approached. The experimental design evaluated the effects of several independent variables: alternative active warning devices (alternative A versus alternative B for each device); basic active warning devices (device A versus device B versus device C); signal actuation distances (null, long, medium, and short); and day versus night conditions. In addition to driver behavior data, attitudinal data on the effectiveness of the six devices were obtained from each subject. All six active warning devices tested were perceived to be superior to standard active warning devices currently in use at highway-railroad grade crossings. Generally speaking, alternative B of each system (i.e., with skirts, with overhead strobes, and with three white bar strobes) was more effective. Four-quadrant gates with skirts tended to be a superior system in all categories of analysis, while the four-quadrant flashing light signals without strobes were rated the least effective. The relative effectiveness of the remaining devices tended to alternate depending on the category of analysis; there was not a consistent ordering of effectiveness of these systems. The authors recommended that alternative B for each device be field tested at an additional crossing. (*8*)

Heathington, et al. (1988)

As a follow-up to the 1984 project, in 1988 the FHWA sponsored a study (*9*) to evaluate a number of innovative traffic control devices at grade crossings. One such device was a system that utilized four-quadrant gates with skirts. The prototype consisted of standard post-mounted flashing light signal assemblies with 12-inch roundels and short-arm gates installed in each of the four quadrants of the crossing. Because of the four-quadrant configuration, the recommended flash pattern for the three lamps on each gate arm was changed from steady burn for the tip lamp and alternate flash for the other two lamps to steady burn for the roadside edge lamp and alternate flash for the two lamps over the roadway.

The laboratory test prototype had a skirt assembly that utilized uniformly spaced vertical strips and a horizontal bar at the bottom. The top horizontal bars were standard fiberglass gate arms that could be adjusted from 6.0 to 7.8 m (20 to 26 ft) in length. Vertical strips were spaced 200 mm (8 in) apart (250 mm [10 in] from center to center) and made of 3.2 mm (1/8 in) thick aluminum plating. Each strip was 50 mm (2 in) wide and 750 mm (30 in) long. The bottom horizontal bars were made of 50 mm by 100 mm (2 in by 4 in) aluminum studding 3.0 m (10 ft) in length. Red and white reflectorized high-intensity sheeting was taped onto the vertical strips and the bottom horizontal bar in 400 mm (16 in) strips. Thus, in addition to the skirt assembly appearing as a more formidable obstacle than a normal gate arm, the additional reflectorized material greatly increased the warning device's conspicuity (the reflective surface of the gates with skirts is approximately six times greater than that of a normal gate arm).

This design worked well for laboratory testing, but researchers made modifications to the field test prototype for several reasons. Because the connectors for the horizontal bars and vertical strips were designed to facilitate changing between alternative configurations in the laboratory study, they were not reliable on a day-to-day basis; the whipping action caused by gusts of high wind would routinely disconnect several of the vertical strips. In addition, repeated use tended to twist and subsequently bind the connectors such that the skirt assembly would not drop properly when the gate arm was lowered. Second, in the upright position, the vertical strips tended to overlap and lay on top of one another, thus creating numerous long, flat surfaces susceptible to snow and ice accumulations, and possible adhesion to one another. Such an event could hinder their dropping properly and add significant weight to the gate arm and skirt assembly. Finally, standard aluminum or fiberglass gate arms (single bar designs) were not rigid enough to support the 7.2 m (24 ft) length of the skirt assembly required at the test site.

To overcome these problems, a new design was adopted for field testing. The top horizontal bar was identical in shape and size to a standard wooden gate arm. This ensured that special mounting and/or adaptor brackets would not have to be fabricated for the field studies. The gate arms' existing X-shaped cross braces were replaced by U-shaped braces to allow the entire skirt assembly to fold inside the gate arm when in the upright position. All horizontal and vertical members were made of kiln-dried redwood, sealed and painted to industry standards, and covered with 400 mm (16 in) strips of red and white high-intensity reflective sheeting. The number of vertical strips was reduced, and the spacing of the remaining strips was adjusted such that there was no contact between them when the gate arm was in the upright position. The resultant loss of reflectorized vertical surface area was compensated by the addition of a second horizontal bar. To preclude the horizontal bars touching one another in the upright position, they were mounted on opposite sides of the vertical strips. The prototype device was 9.0 m (30 ft) in length and 1.0 m (3.5 ft) in height when deployed, and it weighed approximately 63.5 kg (140 lb). (*9*)

Based on the field test results, the four-quadrant gate system outperformed standard two-quadrant gates in several key measures and proved to be practical and cost-effective under a variety of conditions. The researchers concluded that the system substantially increased the safety of the crossing compared to the original two-quadrant gates. Gate violations were completely eliminated in the field test, and there was no apparent effect on reaction times or deceleration rates at the crossing. No vehicles were trapped on the tracks, the new gates did not interfere with emergency vehicles, and no public complaints were received concerning the use or operation of the new system. The wooden gate arms performed adequately under adverse weather, although modifications were recommended to the skirts to make them more durable against contact with vehicles. Standard two-quadrant gate systems could be retrofitted easily, and the safety benefits outweighed the added cost of installation and maintenance. The researchers recommended consideration of four-quadrant gates with skirts at specific types of crossings: crossings on four-lane undivided roads; multi-track crossings where the distance between tracks is greater than the length of a motor vehicle; crossings without train predictors where train warning times are long and variable; crossings where there are hazardous materials trucks, school buses, or high-speed passenger trains; and crossings with consistent gate arm violations or continuing accident occurrences. (*9*)

Bowman (1987)

The FHWA sponsored a project to develop and test prototype active advance warning devices (AAWDs) for use with existing train detection circuitry and associated railroad crossing signals. The goal of the project was to develop a simple, relatively inexpensive device that would have high conspicuity, have a readily understandable and unambiguous message, and conform to current signing practices. Based on these criteria, three candidate devices were selected for this study (*10*), which consisted of three principle components: a primary message sign with optional directional arrows, a supplemental sign with the message “Watch For Trains,” and a pair of alternately flashing yellow beacons positioned one above and one below the primary and supplementary signs. The first primary sign was a 48-inch version of the standard W10-1 warning sign specified in the MUTCD; no directional arrows were used with this sign. The second primary sign was a yellow diamond-shaped sign with a black legend; this sign incorporated a red X, bracketed by two Rs to form the "R X R" symbol. The X on the second sign was flattened to 60 degrees to increase conspicuity and provide room for insertion of directional arrows. The third primary sign consisted of a yellow diamond-shaped sign with a black legend, incorporating a miniature facsimile of the standard W10-1 with red upper and lower quadrants on a yellow background. This sign was intended for use on horizontal curves and contained a curve symbol placed above the W10-1 facsimile.

The study was conducted at four sites where sight restrictions on the approach resulted in an insufficient safe stopping distance. The train detection circuitry at each site was modified to provide train activation of each advance warning device approximately 10 seconds before the activation of the at-grade warning system. Each speed profile analysis during the activated state indicated that the alternately flashing beacons produced a significant decrease in vehicle velocity. Similar analysis, during the unactivated state, revealed that there was no significant difference in vehicle velocities resulting from the use of different primary signs. These results indicated that the test configuration that used the 48-inch standard W10-1 railroad advance warning sign would be effective in providing motorists the required advance warning. (*10*)

Russell (1992)

A significant number of projects were begun in the early 1990s to develop innovative low-cost traffic control devices at highway-railroad grade crossings. Researchers compiled a summary of some these projects and devices to provide a single source of information on new developments. (*11*) They divided this summary into three main parts: a general literature review of innovative devices at passive crossings; a review of devices currently being used, promoted, or developed; and a brief summation of other ongoing studies.

The literature review focused on driver recognition of advanced warning signs, crossbuck signs, and the use of illumination. According to the literature, there is a need to further educate drivers on the meaning of the warning and crossbuck signs, and there is a lack of guidance on the proper action expected at passive crossings compared to active crossings. A number of suggestions were made concerning the development of separate sets of devices for passive and active crossings and supplemental messages on advanced warning signs. Illumination was described as a low-cost option that could be utilized to improve safety under nighttime conditions, particularly in locations where there is a significant occurrence of vehicles striking trains.

The discussion of specific devices that were currently being tested included the Conrail device, retroreflective trackside objects, a passive warning sign, and variable-aspect signs. The Conrail device consists of a three-panel, retroreflective and reflecting device to be installed on the post below the crossbuck sign. This design has a triangular, three-dimensional configuration with "YIELD" on the center panel and reflective diagonal stripes on the two side panels. The study involving retroreflective trackside objects tested the use of high-intensity retroreflective materials on sign posts and delineators to improve nighttime visibility. Burlington Northern Railroad partnered with 3M Corporation to develop a "passive warning sign," which appears to light up as a train approaches. The design of the sign allows the sign to capture the light from the train's headlight and redirect it toward oncoming vehicles, displaying a warning message. Variable-aspect signs, although they are stationary passive signs, appear to move or change as the driver's angle of view changes. These signs can be used to create more visually noticeable messages to alert the driver of the upcoming crossing.

Additional studies in progress concerned the use and testing of other variations of crossbuck designs, reflective devices, and illumination. Some studies focused on conspicuity and driver's understanding of the devices, while others examined the effects of driver education. The author offered his own personal conclusion that there were two major problems that existed in relation to passive crossings. The first was identification of the crossing, both of its existence and its status as a passive crossing, particularly at night. The second problem was full understanding of the crossing's significance, that is, that full responsibility for safe passage over a passive crossing rests with the driver. It was the author's belief that greater conspicuity was needed, especially at night, but that conspicuity needed to be associated with something unique to passive crossings. Driver education and information were seen as key to accomplishing this goal. (*11*)

Synthesis 186 (1993)

As part of the synthesis program authorized by the National Cooperative Highway Research Program (NCHRP), the Transportation Research Board (TRB) compiled a synthesis of information on supplemental advance warning devices. (*12*) The devices included in this report were devices that had been applied and were in keeping with accepted traffic engineering principles, but were not included in the MUTCD. Both active and passive warning devices were presented in a number of general categories, including rail-highway grade crossings. The devices included in this category were divided into two groups: crossing characteristics and approaching trains.

Devices for crossing characteristics are installed at or in advance of railroad crossings to warn motorists of stop control at the crossing, of rough or skewed crossing surfaces, or of unusual crossing geometrics. There were 11 devices included in this group, all of which were passive signs, and a large number of which depicted various geometric configurations with grade crossings and intersections. Another device was a large rectangular sign directed to drivers of large trucks, indicating the presence of a crossing located at the bottom of a grade and around a curve. Other devices warned of uneven tracks or rough surfaces at the crossing, and some included advisory speed plates. Also included in this group is an earlier version of the Low-Clearance Crossing sign, since approved for inclusion in the 2000 MUTCD. Three of the 11 devices in this group, including the Low-Clearance Crossing sign, were considered to be nonstandard by the edition of the MUTCD in effect at that time, because of the use of symbols or combinations of symbols not approved for use.

Devices for approaching trains are used to warn motorists of approaching trains at railroad grade crossings and are installed either at the crossing or in combination with the standard Railroad Advance Warning sign (W10-1). All four of the devices in this group were active devices, activated by train detection circuits. The first device in this group was a changeable message sign mounted on a signal mast arm where a railroad crossing is adjacent to an intersection at which a right turn on red is normally permitted. This sign prohibits this movement during the presence of a train, displaying the message “NO RIGHT TURN ON RED” until the train clears the crossing. The second device in this group was simply a W10-1 sign with a flashing yellow beacon installed above it; the beacon is activated approximately 30 seconds prior to the train reaching the crossing. The third device was a W10-1 sign with a beacon on the left and right sides, mounted above a text sign stating “TRAIN APPROACHING WHEN FLASHING.” This device is located on approaches to crossings with insufficient sight distance, and is located at a distance equal to the safe stopping distance plus 15 m (50 ft) from the tracks. The final device in this group consisted of a W10-1 sign mounted in conjunction with a supplementary “WATCH FOR TRAINS” message plate and two alternately flashing beacons mounted above and below the signs. The flashers are activated when a train passes over the train detection circuitry approximately 10 seconds prior to activation of the at-crossing warning system.

The studies conducted in conjunction with the development of these devices indicated favorable results in locations where the devices were tested. (*12*)

Fambro, et al. (1997)

The objective of this three-year research project, sponsored by TxDOT and FHWA, was to develop, test, evaluate, and recommend improved methods for communicating with drivers at both active and passive highway-railroad grade crossings. (*13*) Researchers developed four study methods to accomplish this objective. First, a survey of driver comprehension of highway-railroad grade crossings was completed. This survey was followed by in-vehicle observations of driver behavior at grade crossings. A third study included the evaluation of experimental passive sign systems previously installed at several operational grade crossings; driver reaction to these signs was evaluated. Finally, the study looked at the development of other enhanced traffic control devices.

The driver comprehension survey found a lack of understanding of driver requirements and responsibilities at passive and active grade crossings. Drivers also showed a lack of understanding for the railroad advance warning sign and crossbuck.

Survey participants suggested that more public education would help improve safety at grade crossings. Observation of drivers' actions indicated that most drivers who reflected a general understanding of safe driving behavior in the survey did not actually perform as they said they should or would when approaching a crossing. Many drivers initiated looking behavior within 5 m (16.4 ft) of the crossing, which may not allow enough time to avoid a potential collision, especially without speed reduction on the approach.

The portion of the project that evaluated experimental passive sign systems utilized two specific designs. The first experimental sign system tested consisted of a standard size YIELD sign with a supplementary message plate containing the words TO TRAINS. This sign was located at the grade crossing near the crossbuck. The second sign system consisted of a 900 mm (36 in) yellow high-intensity-backed diamond warning sign with a black train locomotive symbol. The sign also contained a yellow supplementary message sign that read LOOK FOR TRAINS. This sign system was placed on the approach to the grade crossing between the railroad advance warning sign and the crossbuck. Each sign system was installed at multiple grade crossings in two different Texas counties. Though a reduction in crashes could not be measured directly, two surrogate measures of effectiveness were observed to determine the effectiveness of both sign systems. Researchers determined that the implementation of either sign system may initially increase speed reductions and decrease speeds on the approaches to some grade crossings; however, the data suggested that over time drivers would return to their previous behavior. The data also suggested that drivers might have understood the YIELD TO TRAINS sign system better than the LOOK FOR TRAINS sign system. Drivers with the former system showed greater speed reductions and some significant increases in looking behavior. The latter sign system did not have as great an impact on approach speeds and produced no significant improvement in looking behavior.

In the final portion of the project, two different enhanced active traffic control devices were evaluated and compared to a standard W10-1 advance warning sign. The two devices were a W10-1 sign with a flashing beacon and a W10-1 sign with a strobe light. According to the 1988 MUTCD, a hazard identification beacon is one or more sections of a standard signal head with a flashing circular yellow indication in each section. One typical application of flashing beacons cited in the 1988 MUTCD is the use of the flashing beacon supplemental to railroad advance warning signs. The beacon used for this study was 300 mm (12 in) in diameter and mounted on the same post as the advance warning sign above the sign. The supplementary strobe light evaluated in this research was 65 mm (2.5 in) in diameter and flashed at a rate of 1.4 flashes per second. Originally, the strobe was mounted on the signpost below the sign but later was moved above the sign, similar to the beacon. The beacon was set to flash continuously, while the strobe was activated by approaching vehicles.

This study was conducted to determine if the supplemental strobe light would result in any adverse driver reactions. Therefore, the measures of performance that were evaluated included driver head movement, braking reaction, and steering reaction. An in-vehicle observer accompanied drivers as they drove through a test course and were exposed to each of the three railroad advance warning signs. The in-vehicle observer recorded whether each driver reacted to the sign and if so, whether the reaction was severe and potentially dangerous. To determine if driver comprehension of the sign systems was consistent with its intended meaning, study drivers were asked to participate in a group discussion of the experimental devices after completing the test course.

Based on the findings of this study, the researchers concluded that none of the sign systems caused any adverse driver reactions, and no evidence was available to indicate the systems affected driver head movement or looking behavior. Braking behavior did vary with the specific sign system, with drivers exhibiting more caution at the enhanced signs. Based on drivers' responses, the beacon-enhanced sign was preferred to gain the attention of daydreaming drivers and warn of an upcoming grade crossing; however, both of the enhanced systems were preferred to the standard sign. All drivers understood the meaning of the standard railroad advance warning sign but became confused by its meaning upon the addition of the supplemental lights. Based on these results, further field testing of the vehicle-activated flashing strobe light was commissioned, with the addition of a supplementary sign plate stating "LOOK FOR TRAIN AT CROSSING." (*13*)

Train Whistle Bans

Train whistles, horns, and bells are warning devices that enhance railroad safety by giving motorists an audible indication of a train's proximity. The Federal Railroad Administration (FRA) requires that each lead locomotive in a train have an audible warning device. However, FRA's regulations do not specify when train audible warning devices should be sounded. Individual railroads and state laws mandate those requirements. Typically, railroad operation procedures require engineers to sound train horns or whistles at most highway-rail grade crossings. (*14*)

Whistle or horn use is an important deterrent to highway-rail crossing accidents in densely populated areas. However, various groups have sought ways to reduce or ban the use of train whistles in certain areas. One such ban was enacted by the Florida State Legislature. Effective July 1, 1984, local jurisdictions were allowed to establish nighttime (10:00 p.m. to 6:00 a.m.) train whistle bans at crossings equipped with active warning devices. The bans only applied to certain crossings on one particular rail company's line, specifically, the Florida East Coast Railway Company (FEC). Eventually, seven counties and 12 cities established bans, which affected 511 FEC public crossings by the end of 1984. (*15*)

FRA received a congressional request to study FEC's nighttime train accident rate. Specifically, FRA was asked to determine if there was any correlation between those areas that had whistle bans and the number of highway-rail crossing accidents. Using a 1984-89 study period, the agency found that FEC's nighttime accident rate at these 511 crossings increased 195 percent after the bans were imposed, while daytime accidents at the same crossings remained virtually unchanged. (*14*)

Following their investigation, FRA issued Emergency Order No. 15 (EO 15) on July 26, 1991. This order required FEC to follow rules requiring train horns to be sounded at highway-rail crossings. This order was amended to allow whistle bans under certain conditions that would be certified by the Florida Department of Transportation. FRA proposed the establishment of "quiet zones," where the length of the zone between non-enhanced at-grade crossings would be at least 800 m (0.5 mi). There were five qualified enhancements defined by FRA: permanent closure of the highway-rail crossing through grade separation; nighttime closure of the crossing; use of a four-quadrant gate system; use of gates with median barriers; and one-way pairing of adjacent streets. Following the enactment of EO 15, nighttime accidents decreased 68.6 percent, returning to pre-whistle ban levels. This indicated that prohibiting train horns had significantly increased the risk of accidents. (*14*)

In order to gain a better understanding of national conditions, and in consideration of future rulemaking, FRA announced it would conduct a national study of whistle bans to determine how many crossings were affected and examine the accident histories of those crossings. The study was performed using data from a survey conducted in 1992 by the Association of American Railroads (AAR), which identified crossings with whistle bans. The study included 2122 public at-grade crossings on 17 railroads located in 27 states. Ninety-four percent of the whistle bans at these crossings were effective 24 hours a day, while fewer than 6 percent were nighttime-only. As of the 1992 survey, the number of these crossings with whistle bans had reportedly decreased by 721, due to cancellation by public officials or a decision to ignore the ban by the railroads. This left 1401 crossings remaining with bans. The cancellation of bans enabled FRA to make direct comparisons of the number of accidents during the bans and during equal time intervals when the bans were not in effect. There were 12 "before and after" case studies, involving eight railroads and 831 crossings, which showed that the overall accident rate declined 38 percent when the whistle bans were cancelled.

In addition, an analytical comparison of 1222 crossings subject to whistle bans from 1989 to 1993 against all other 167,000 public grade crossings in the national inventory was made. The 1222 crossings were divided into 10 groups of nearly equal size based on similar estimated accident frequencies; within each risk level, the accident histories of the crossings were tabulated. A similar procedure was followed for the other 167,000 crossings. In nine of the ten risk levels, the group of crossings with whistle bans had accident frequencies significantly higher than the corresponding risk level group for the national population. Overall, crossings with whistle bans had an average of 84 percent more accidents than crossings without bans. The results of this study indicated that the safety risks associated with whistle bans were not unique to Florida. (*14*)

After reviewing the Florida study, Congress passed the Swift Rail Development Act on November 2, 1994. This act requires the use of locomotive horns at grade crossings, but gives FRA the authority to make reasonable exceptions. Based on the results of the nationwide study, and continued monitoring of crossing conditions since the study, FRA has proposed a nationwide rule largely equivalent to the guidelines established in EO 15. The proposed rule would require that horns be sounded at every public highway-rail crossing. FRA has provided an exception to this requirement for crossing within a designated "quiet zone." If all crossings within that zone are equipped with approved supplementary safety measures in addition to conventional gates and flashing lights, locomotive horns will not need to be sounded, subject to the rule requirements. The rule further provides that if a community wishes to establish a quiet zone, but it cannot, for some reason, fully comply with the rule's requirements for supplementary safety measures at every crossing within the zone, it may apply to the FRA with its proposed program of safety measures. FRA will evaluate the community proposal to determine if the safety measures will compensate for the lack of a horn. Finally, the rule provides a very limited exception to the requirement that supplementary or alternative safety measures must be in place if locomotive horns are silenced. (*16*)

As required by the Swift Rail Development Act, any regulations issued pursuant to the act shall not take effect for one year following the date of publication of the final rule. As a result, the regulation's requirements to sound the locomotive horn (absent establishment of a quiet zone) will not be effective until one year after publication of the final rule. The one year period, in addition to the period between publication of this proposed rule and the final rule, will enable communities to assess options and plan for those actions deemed best for that particular community. FRA anticipates that during the one year between final rule publication and its effective date, communities will wish to initiate the administrative process involved in establishing quiet zones so that, if desired, they can have quiet zones in place exactly one year after publication of the rule. Therefore, FRA anticipates that for administrative purposes only, the final rule will have an effective date 60 days after publication. FRA is currently requesting comments on this proposal. (*16*)

Conclusions

The *Manual on Uniform Traffic Control Devices* has many standards and guidelines concerning traffic control at highway-railroad grade crossings. There are also significant recommendations dealing specifically with signal preemption. In addition, a great deal of research has been done to develop new devices or improve existing ones. Based on the results obtained from these research efforts, there appears to be a significant issue concerning drivers' understanding of the meaning of these devices, as well as their understanding of what their responsibilities are as drivers. Much of the research focused on conveying a clearer message to drivers that it is necessary to look thoroughly for trains at crossings, and to yield to trains when they are present or approaching. Other research was concentrated on making crossings more visible and providing drivers as much information about the crossing as possible. Currently, the crossbuck sign and the advance warning sign are standard devices at crossings, and they are commonly recognized as applying to crossings. However, their exact meaning is often unclear to many drivers, particularly when differentiating between actively and passively controlled crossings. Because these two signs are easily recognizable as unique to highway-railroad grade crossings, their continued use is very important. However, the research indicates differing opinions as to whether response to these signs should be simply improved with better driver education, or whether the designs should be supplemented or even replaced with other signs.

There appears to be a significant level of standardization concerning gate arms at highway-railroad grade crossings. Unfortunately, documentation for those standards is difficult, if not impossible, to find. This may be partly attributed to the fact that the design of gate arms has been largely unchanged for many years. The standards that were written 20 years ago are still applicable, but few seem to know exactly what they are or who wrote them. Many of the people who were contacted for information on current practices and standards indicated that there was a set of standards that had been defined by at least one organization, but no one knew exactly which organization it was or what those standards were. It is possible that manufacturers and designers have been producing and installing gate arms the same way for so long that the standards have simply become a kind of common knowledge. As a result, it is not easy to find documented standards to use for reference.

Each of the documents referenced in the section on gate arms either refers to another document or contains the same information as another document. While this is good for providing consistent guidelines, it becomes difficult to determine the original source of these guidelines and the reasons for them. Perhaps the updated standards in the 2000 edition of the MUTCD will help to reestablish a common set of standards for design and implementation. This reestablishment of common standards will then benefit researchers in future efforts because it will provide them with a defined benchmark with which to compare their new designs. A great deal of research has been performed to date, with significant results; if these previous efforts can be used as a basis for future projects, the benefits will be much greater, and can be used to improve both safety and efficiency.

CHAPTER 4
INTERCONNECTION

When a highway-rail grade crossing is located near a signalized intersection, it is possible that queues from the intersection could extend over the grade crossing and potentially cause stopped vehicles to become trapped on the tracks. To prevent this from happening, traffic signals located near highway -rail grade crossings need to be preempted when trains approach in order to clear vehicles off the tracks before the train arrives.

Preemption of traffic signals is normally achieved through an electrical interconnection circuit between the railroad grade crossing warning system and the highway traffic signal controller assembly. According to the 2000 MUTCD Section 8D.07 (*1*):

> "If preemption is provided, the normal sequence of traffic control signal indications shall be preempted upon the approach of trains to avoid entrapment of vehicles on the highway-rail grade crossing by conflicting aspects of the traffic control signals and the highway-rail grade crossing flashing-light signals.
>
> This preemption feature shall have an electrical circuit of the closed-circuit principle, or a supervised communication circuit between the control circuits of the highway-rail grade crossing warning system and the traffic control signal controller. The traffic control signal controller preemptor shall be activated via the supervised communication circuit or the electrical circuit that is normally energized by the control circuits of the highway-rail grade crossing warning system. The approach of a train to a highway-rail grade crossing shall de-energize the electrical circuit or activate the supervised communication circuit, which in turn shall activate the traffic control signal controller preemptor. This shall establish and maintain the preemption condition during the time the highway-rail grade crossing warning system is activated, except that when crossing gates exist, the preemption condition shall be maintained until the crossing gates

are energized to start their upward movement. When multiple or successive preemptions occur, train activation shall receive first priority."

The geometric design of any signalized intersection near a highway-rail grade crossing should consider interconnection and preemption.

Background

The most important decision about interconnection is whether it should be provided. According to Section 8C-6 of the 1988 MUTCD (*17*), preemption (and consequently interconnection) should be considered when the distance between the highway-rail grade crossing and the signalized intersection is less than 60 m (200 ft). According to a recent NCHRP Synthesis of *Traffic Signal Operations Near Highway-Rail Grade Crossings* (*18*), many state departments of transportation believe that the need for preemption should be based on a detailed queuing analysis, considering items such as roadway approach traffic volumes, number of lanes, nearby traffic signal timing, saturation flow rates, motor vehicle arrival characteristics, motor vehicle classes, etc., rather than a prescribed distance such as 60 m (200 ft). The 1997 ITE *Recommended Practice on the Preemption of Traffic Signals At or Near Railroad Grade Crossings with Active Warning Devices* (*5*) also highlights the need for preemption to be based on a detailed queuing analysis. In the 2000 MUTCD, Section 8D.7 provides additional guidance over the 1988 MUTCD by recommending that "coordination with the highway-rail grade crossing warning system should be considered for traffic control signals located more than 60 m (200 ft) from the crossing. Factors should include motor vehicle traffic volumes, approach speeds, and queue lengths." (*1*)

Even though the above-mentioned guidelines focus on traffic operations and traffic control devices, they should form the basis of geometric design guidelines to ensure compatibility between geometric design, traffic control, and traffic operations.

Recommendations

The following recommendations are applicable to the geometric design of intersections near highway-rail grade crossings.

Clear Storage Distance

The distance between the intersection and the highway-rail grade crossing should be measured in accordance with the definition of the "Clear Storage Distance," as defined by the Technical Working Group (TWG) of the United States Department of Transportation (USDOT) Grade Crossing Safety Task Force (*19*):

> *Clear Storage Distance*: The distance available for vehicle storage measured 2 m (6 ft) from the rail nearest to the intersection to the intersection STOP BAR or the normal stopping point on the highway. At skewed crossings and intersections, the 2 m (6 ft) distance shall be measured perpendicular to the nearest rail, either along the centerline, or right edge line of the highway, as appropriate, to obtain the shorter clear distance.

Figure 9 shows how the Clear Storage Distance is measured at a skewed intersection.

Designing for Interconnection

The decision whether to design for an interconnection between the highway traffic signal controller assembly and the railroad grade crossing warning system should be based on the guidelines in the 2000 MUTCD, although designers and engineers should consult the most current edition of the Texas MUTCD for specific information pertinent to Texas. According to Section 8D.7 of the 2000 MUTCD, preemption should be provided when a highway-rail grade crossing with an active traffic control system is located within 60 m (200 ft) of an intersection or mid-block location controlled by a traffic signal. Therefore, all intersections with active crossings and a Clear Storage Distance of 60 m (200 ft) or less should be designed for interconnection. (*1*)

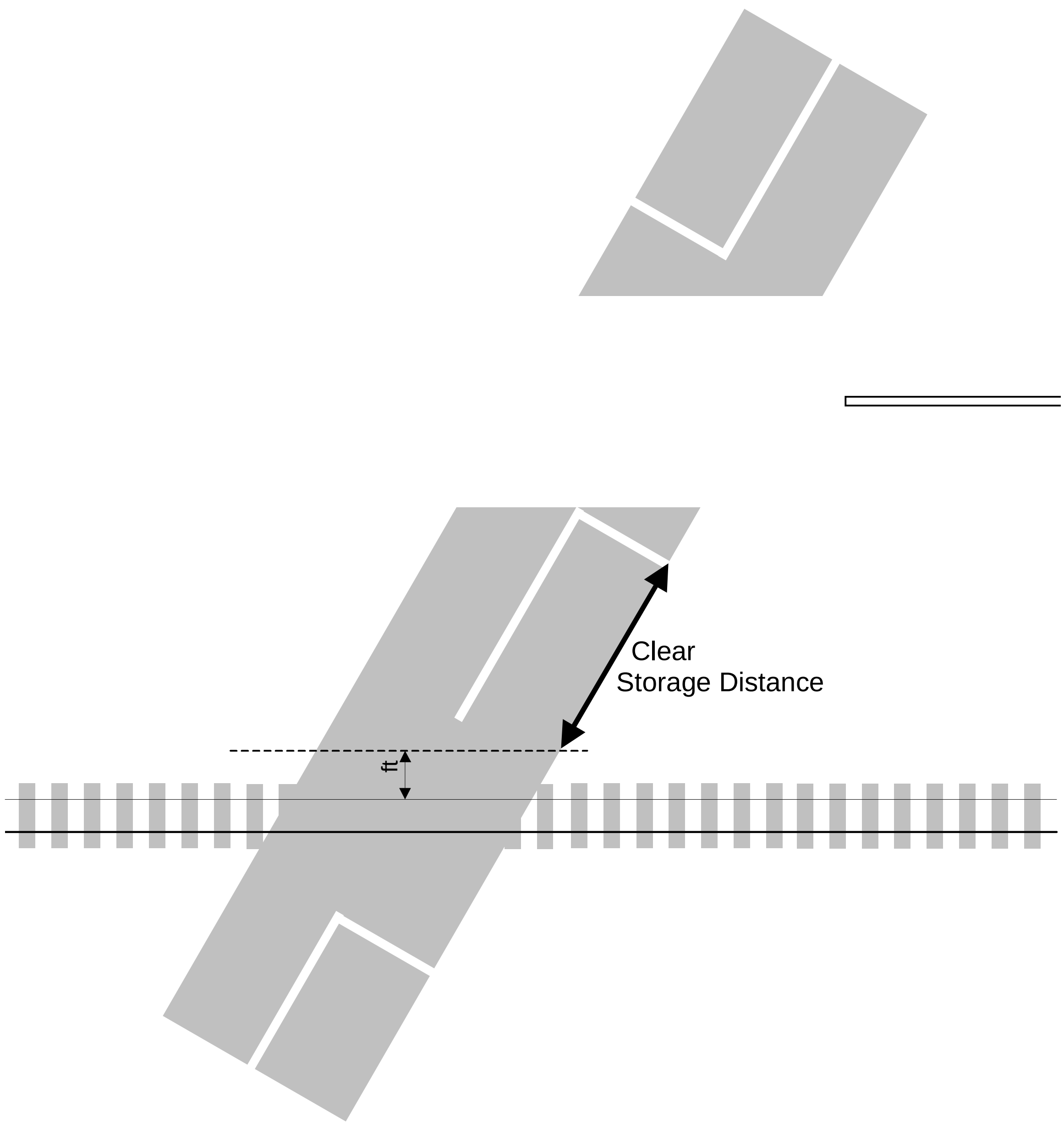


Figure 9. Clear Storage Distance at Skewed Crossings.

The ITE Recommended Practice (*5*) and 2000 MUTCD (*1*) recognize that preemption may be required at traffic signals located more than 60 m (200 ft) from the crossing, as determined by queue lengths, traffic volumes, and approach speeds. The ITE guidelines recommend that a queue length analysis be conducted to determine the maximum extent of the queue. Therefore, the design traffic volume on the approach crossing the tracks should be used to perform a queue length analysis to determine the extent of the queue. If the extent of the queue exceeds the Clear Storage Distance in more than 5 percent of signal cycles during the design hour, the intersection should be designed for interconnection. The queue length that would be exceeded in 5 percent of signal cycles corresponds to the 95th percentile queue length, which can be estimated either through simulation or analytical methods. Regardless of the methodology used, a queue analysis requires at least the following information:

- lane layout,
- design volume per movement,
- signal cycle length,
- effective green time per movement, and
- saturation flow per movement.

If a simulation analysis is done, these values can be entered into a simulation model such as CORSIM (CORridor SIMulation) (*20*), which will simulate the resulting queue.

It is also possible to use the results from a simulation analysis by Oppenlander and Oppenlander (*21*) that produced a set of tables of queue length distributions (including 95th percentile queue) as a function of traffic volume, cycle length, and effective green time. The designer should keep in mind that the Oppenlander tables are only applicable on a lane-by-lane basis, so it is the responsibility of the designer to determine the traffic distribution across lanes and to identify the critical lane that would result in the longest queue.

The 95th percentile queue can also be estimated analytically through the following equation (*22*):

$$N_{95} = \frac{qC(1-\lambda)}{(1-y)} + \frac{0.5x^2}{(1-x)} + 0.475\sqrt{\frac{(qC)^2(1-\lambda)^3(1+3\lambda-4y)}{(1-y)^2} + \frac{x^3(4-x)}{(1-x)^2}} \qquad (1)$$

where

N_{95} = 95th percentile queue (vehicles per lane)

q = average arrival flow rate (vehicles per second per lane);

C = cycle length (seconds);

λ = green time ratio, $\lambda = g/C$;

g = effective green time (seconds);

y = flow ratio, $y = q/s$;

s = saturation flow rate (vehicles per second per lane), assume a value of 0.5;

x = degree of saturation, $x = (qC)/(sg)$, $x < 1.0$.

Note that this equation applies to the critical lane and is only valid for undersaturated conditions ($x < 1.0$), where demand (qC) is less than capacity (sg).

Equation 1 requires that the designer select realistic values of the signal cycle length (C) and the effective green time (g) for the analysis. If the traffic signal operates in a coordinated system, the cycle length will be the same as that of the surrounding traffic signals, and the cycle length will depend on factors such as traffic volume, traffic speed, and signal spacing. The effective green time will typically be long enough to service the design volume at a degree of saturation (x) less than 0.90, but the effective green time will depend on the geometry of the intersection and the demand on approaches not crossing the tracks. In the absence of any other information, a value of 0.80 can be used for the degree of saturation.

The average arrival flow rate (q) applies to the critical lane design volume and can be calculated by dividing the critical lane design volume (in vehicles per hour per lane - or *vphpl*) by 3600. If the saturation flow rate (s) is not known, a value of 0.5 vehicles per second per lane (equivalent to 1800 vehicles per hour per lane) can be used.

Note that Equation 1 produces queue estimates in vehicles per lane. To get the actual length of the queue, it is necessary to multiply the queue estimate with the average queue space per vehicle, taking into account the vehicle mix. The following equation can be used:

$$L_{95} = N_{95} \sum_{i=1}^{n} p_i L_i \qquad (2)$$

where

L_{95} = 95th percentile queue length (ft)

N_{95} = 95th percentile queue (vehicles per lane)

n = number of vehicle classes in queue

p_i = proportion of vehicle class i (by volume)

L_i = queue space of a vehicle of class i (ft per vehicle)

In the absence of better information, the values of L in Table 1 may be used:

Table 1. Queue Space by Vehicle Class.

Vehicle Class	Vehicle Queue Space L
Car	25 ft
Single Unit Truck	36 ft
Truck Combination	66 ft

Equation 1 can be used to determine the 95th percentile queue when the lane volume, cycle length, and effective green time are known. Note that the queue is given in vehicle units, so that Equation 2 must be applied to calculate the actual length of the queue.

Conclusions

The equations provided in this chapter may be used directly to determine the 95th percentile queue; alternatively, tabulations of resulting queues have been developed and provided in a companion report, *Design Guidelines for At-Grade Intersections Near Highway-Railroad Grade Crossings.* (*39*) Interconnection between active grade control at the highway-railroad grade crossing and traffic signals present at a nearby intersection should be implemented if spacing between them is less than 60 m (200 ft); interconnection should also be considered if the spacing is greater than 60 m (200 ft) but predicted queues are projected to exceed the available storage space.

Because traffic projections used in geometric design typically are set at 20 years and the interconnection of traffic signals and active grade control may cost a substantial amount, consideration may be given to phasing in the implementation. The designer might consider providing only interim measures such as the installation of conduit or interconnection circuits, rather than actual preemption until traffic volumes actually approach those projected for design.

CHAPTER 5
CHANNELIZATION

Intersections near highway-railroad grade crossings require special attention to coordinate the movements of vehicle, train, and pedestrian traffic. One tool that can be used to improve safety and efficiency is channelization. According to AASHTO's *Policy on Geometric Design of Highways and Streets* (*4*), channelization is defined as "the separation or regulation of conflicting traffic movements into definite paths of travel by traffic islands or pavement marking to facilitate the safe and orderly movements of both vehicles and pedestrians. Proper channelization increases capacity, improves safety, provides maximum convenience, and instills driver confidence." However, large -scale channelization is not a solution for every problem. Improper or excessive channelization can reduce safety and capacity. Many times the addition of a turning lane, median, or island is sufficient to accomplish the desired improvements. With the added conflict of railroad traffic, care must be taken to ensure that channelization provides guidance, not confusion. Following is a review of principles and guidelines concerning intersection channelization in general, as well as some specific information regarding channelization solutions near railroad crossings.

Background

AASHTO's *Policy on Geometric Design of Highways and Streets* (*4*) list several factors for which channelization is generally warranted:

- The paths of vehicles are confined by channelization so that not more than two paths cross at any one point.
- The angle and location at which vehicles merge, diverge, or cross are controlled.
- The amount of paved area is reduced and thereby decreases vehicle wander and narrows the area of conflict between vehicles.
- Clearer indications are provided for the proper path in which movements are to be made.

- The predominant movements are given priority.
- Areas are provided for pedestrian refuge.
- Separate storage lanes permit turning vehicles to wait clear of through-traffic lanes.
- Space is provided for traffic control devices so that they can be more readily perceived.
- Prohibited turns are controlled.
- The speeds of vehicles are restricted to some extent.

Intersections at highway-railroad grade crossings can involve several of these warranting factors, which makes channelization a possible solution for improvements to safety and efficiency. Intersections near crossings are often somewhat complex, and additional indications to motorists concerning the proper path to take are beneficial. In many cases, turning vehicles form queues while waiting for the passage of a train; it can be useful to provide separated lanes for these vehicles to reduce the conflict with through traffic. On multilane roadways, it is often necessary to improve the visibility of traffic control devices; channelization makes space available in the median for that purpose. One of the most important needs of an at-grade crossing is to prevent vehicles from crossing the tracks during the impending arrival of a train; proper channelization can control and restrict the movements of vehicles, confining them until a safe crossing can be attempted.

Design of a channelized intersection usually involves a number of key factors, some of which are: the type of design vehicle, the cross sections of the roadways, traffic volumes (vehicle and train), vehicle speed, train speed, type and location of traffic control devices, right-of-way, and terrain. Taking these factors into account, AASHTO (*4*) has identified certain principles that should be followed in the design of a channelized intersection:

- Motorists should not be confronted with more than one decision at a time.
- Unnatural paths that require turns greater than 90 degrees or sudden and sharp reverse curves should be avoided.

- Areas of vehicle conflict should be reduced as much as possible. However, merging and weaving areas should be used to keep vehicles within well-defined paths that minimize the area of conflict.
- Traffic streams that cross without merging and weaving should intersect desirably at right angles, with a range of 60-120 degrees acceptable.
- The angle of intersection between merging streams of traffic should be appropriate to provide adequate sight distance.
- The points of crossing or conflict should be studied carefully to determine if such conditions would be better separated or consolidated to simplify design with appropriate control devices added to ensure safe operation.
- Refuge areas for turning vehicles should be provided clear of through traffic.
- Islands used for channelization should not interfere with or obstruct bicycle lanes at intersections.
- Prohibited turns should be blocked wherever possible.
- Location of essential control devices should be established as a part of the design of a channelized intersection.
- Channelization may be desirable to separate the various traffic movements where multiple phase signals are used.

As with AASHTO's warranting factors, several of these principles are particularly applicable to highway-railroad grade crossings. Proper channelization can be used to reduce the number of decisions a motorist has to make, thereby improving safety. Consolidation of traffic movements and separation of turning vehicles can reduce conflicts and confusion, which would improve efficiency. The physical prevention of prohibited turns and movements is often required for smooth operation at a crossing. Channelization allows for the most beneficial placement of control devices with minimal interference to traffic.

Islands

Traffic islands are common tools for achieving channelization objectives. According to AASHTO, an island is a defined area between traffic lanes for control of vehicle movements. Islands also provide an area for pedestrian refuge and traffic control devices. Within an intersection, a median or an outer separation is considered an island. (*4*)

Islands to control and direct traffic movement should guide motorists into the proper channel for their intended route. The confusing traffic movements resulting from large paved areas can be eliminated by conversion of normally unused areas into islands, which provide guidance and reduce the number of decisions that drivers must make. Channelizing islands may be of many shapes and sizes, depending on conditions and dimensions of the intersection.

Channelizing islands should be placed so that the proper course of travel is immediately obvious, easy to follow, and of unquestionable continuity. When designing an island, attention should be given to the driver's field of view. Particular care must be taken where the channelization is on or beyond a crest of a vertical curve, or where there is substantial horizontal curvature on the approach to or through the channelized area. The outlines of islands should be smoothed, curved lines that are easily traversed or straight lines nearly parallel to the line of travel. Where islands separate turning traffic from through traffic, the radii of curved portions should equal or exceed the minimum for the turning speeds expected. Drivers should not be confronted suddenly with an obstructed area in the normal vehicle path but should have adequate advance notice and guidance.

Properly placed islands are advantageous where through and turning movements are heavy. At minor intersections on two-lane highways, however, channelization may be of questionable value, especially in rural areas where small curbed islands are provided. The use of curbed islands generally should be reserved for multilane highways or streets and for the more important intersections on two-lane highways. In or near urban areas where speeds are low and drivers are accustomed to confined facilities, channelization can be expected to work well. Curbed islands generally should not be used in rural areas and at isolated locations. (*4*)

Marked channelization (painting or striping) can be made to increase efficiency and safety and has the advantage of easy modification when warranted by driver behavior. If a more positive barrier is required, curbed islands may be constructed, but the marked channelization may well serve initially to establish the best layout before permanent construction is established. It should be noted, however, that inclement weather (i.e., snow) decreases the effectiveness of marked channelization. (*4*)

In 1985, NCHRP sponsored a project to develop an *Intersection Channelization Design Guide*. (*23*) Included in this guide are instructions for the use of islands. Design of traffic islands must consider their intended site-specific functions. These may include definition of vehicle paths, separation of traffic movements, prohibition of movements, protection of pedestrians, placement of traffic control devices, or a combination of these. Application of design guidelines and standards to reflect these functions involves the following considerations:

- selection of an appropriate island type (raised or mountable, painted or flush),
- determination of the proper size and shape of islands,
- location of the island relative to adjacent traffic lanes or crosswalks, and
- design of the individual elements of the island itself.

As with other channelization elements, these considerations are affected by traffic characteristics such as volume, speed, and environmental factors.

Selection of an appropriate type of traffic island should be based on traffic characteristics, cost considerations, and maintenance needs. Painted (or flush) channelization is appropriate on high-speed rural highways to delineate separate turning lanes and in constrained locations where vehicle path definition is desired but space for larger, raised islands is not available. Flush traffic islands may be used to separate opposing traffic streams on low-speed streets, in lieu of raised channelization in regions of frequent snowfall. Flush traffic islands may also be used as temporary channelization during construction or to test traffic operations prior to installation of raised islands. Flush channelization is not effective in prohibiting or preventing traffic movements, nor is it appropriate for islands intended to serve as locations of pedestrian refuge. (*23*)

Raised traffic islands are necessary where the island has one of the following as a primary function: shield pedestrians from vehicular traffic; locate traffic signals, signs, or other fixed objects; or prohibit or prevent traffic movements. Raised islands may also be appropriate on low- to moderate-speed highways where the primary function is to separate high-volume opposing traffic flows, or at locations requiring more positive delineation of vehicle paths, such as at major route turns or intersections with unusual geometry. (*23*)

The *Intersection Channelization Design Guide* provides the following principles of design for traffic islands: (*23*)

- The proper traffic lanes or turning roadways should appear natural and convenient to their intended users.
- The number of islands should be held to a practical minimum to avoid confusion.
- Islands should be large enough to be effective. Small islands do not function as channelizing devices and tend to present maintenance problems.
- Islands should not be introduced at locations with restricted sight distance or in the middle of sharp horizontal curves.

A good design that follows these principles should take into account a number of factors: design speeds of intersecting highways and turning roadways, cross section of intersecting highways, type and approximate size of island to be used, fulfillment of design objectives, and traffic control.

One particular kind of channelizing island is the median island. Design of median islands generally reflects site-specific geometrics such as angle of intersection and cross section. The following guidelines address good design of median approach islands: (*23*)

- Approach noses should be offset 0.6-1.8 m (2-6 ft) from the through (approach) lanes to minimize accidental impacts. Pavement markings in advance of the nose can be used to transition from the centerline to the edge of the island.
- The shape of the island should be based on design turning paths and the island function. Curvilinear tapers comprised of parabolic or circular curves generally suffice.

- The length of the island should be related to the approach speed. Some agencies recommend a length based on a three-second driving time to the intersection. However, the island length will be affected by available widths, taper designs, and local constraints.
- The width of the island should adequately serve its intended functions. These may vary from access control or separation of conflict to pedestrian refuge or shielding of left-turn lanes.
- Median islands should begin on tangent alignment and on upgrades or well past crest vertical curves. In some cases, it is appropriate to extend a median island to avoid its introduction on a horizontal curve or within an area of limiting sight distance.

Left- and Right-Turn Lanes

AASHTO defines a median left-turn lane as an auxiliary lane for storage or speed change of left-turning vehicles located at the left of a one-directional roadway within a median or divisional island. Accident potential, inconvenience, and considerable loss in efficiency of operation are evident on divided highways where such lanes are not provided. Therefore, median lanes should be provided at intersections and at other median openings where there is a high volume of left turns or where the vehicular speeds are high. (*4*)

Median widths of 6 m (20 ft) or more are recommended by AASHTO at intersections with single median lanes, but widths of 4.8-5.4 m (16-18 ft) permit reasonably adequate arrangements. Where two median lanes are used, a median width of at least 8.4 m (27.5 ft) is desirable to permit the installation of two 3.6 m (12 ft) lanes and a 1.2 m (4 ft) separator. Although not equal in width to a normal traveled lane, a 3.0 m (10 ft) lane with a 0.6 m (2 ft) curbed separator or with traffic buttons or paint lines, or both, separating the median lane from the opposing through lane may be acceptable where speeds are low and the intersection is controlled by traffic signals. Pavement markings, contrasting pavement texture, signs, and physical separators may be used to discourage the through driver from inadvertently entering the wrong lane. (*4*)

Left-turning vehicles are critical to the performance of an intersection. They have potential conflicts with opposing traffic, cross traffic, and through traffic in the same direction; therefore, their treatment has a significant impact on the safety and service of an intersection. The *Intersection Channelization Design Guide* suggests that left-turn lanes should be considered at the planning and preliminary design stages of any new signalized intersection, and provides guidelines and warrants for their installation based on turning volumes, capacities, and approach geometrics. The *Guide* also states that separate left-turn lanes are considered necessary for safe operations at high-speed rural signalized intersections; this is not because of capacity problems, but for the protection of queued left-turning vehicles. For new unsignalized intersections and for reconstruction of existing intersections, the *Guide* provides guidelines and warrants for the implementation of separate left-turn lanes based on factors such as capacity, volume, and accident analysis. (*23*)

The design of left-turn lanes is directly related to their intended functions, characteristics of the highway, and local constraints. Left-turn lanes can provide one or more of the following functions: a means of safe deceleration, a separate storage area for left-turning vehicles in order to optimize signal phasing, and a means of separating movements at unsignalized intersections to reduce left-turn impacts on other traffic flows. Design elements of left-turn lanes include approach taper, bay taper, lane length, lane width, and departure taper. Approach tapers prepare drivers for the upcoming intersection and the left-turn lane. Bay tapers direct left-turning traffic out of the through lane into the turning lane. The length of the lane could be the most important design element, based on prevailing speeds, volumes, and traffic control; the design basis for length could be deceleration, storage, or both. Lane widths should reflect prevailing speeds, volumes, and vehicle mix; 3.6 m (12-ft) lanes are desired, but 2.7 m (9 ft) lanes may function adequately at certain locations. Departure tapers are designed in connection with the left-turn lane on the opposite approach and are used to create a smooth transition back to the design away from the intersection. (*23*)

The use of exclusive right-turn lanes at intersections can also significantly affect operations. Addition of a separate right-turn lane or conversion of a through lane to a right-turn lane can result in improvements to the level of service at an intersection. In terms of safety, special treatment for right-turning vehicles is often less critical than that for left-turning vehicles. Right turns have a smaller potential for conflicts and less influence on other traffic flows than left turns. However, there are conditions where the use of exclusive right-turn lanes may be beneficial by removing decelerating turning vehicles from the through traffic lanes.

For low-speed urban intersections, engineers generally focus on capacity analyses and accident experience when determining the need for right-turn lanes. In rural areas, the focus shifts primarily to combinations of through and right-turning volumes in order to find a solution to potential rear-end conflicts. Design of right-turn lanes is similar to that of left-turn lanes. A right-turn lane can fulfill one or more of the following functions: a means of safe deceleration, a separate storage area for right-turning vehicles in order to optimize signal phasing, and a means of separating movements at unsignalized intersections. Design elements of interest include the departure taper, lane length, lane width, and recovery area. (*23*)

Functional requirements for right-turn lanes are similar to those for left-turn lanes. When the principle function of the lane is to provide for deceleration, the *Intersection Channelization Design Guide* suggests the design should be based on deceleration in gear for three seconds, followed by comfortable braking. With right turns, it may be appropriate to assume that braking continues not to a stop, as with left turns, but rather to the design speed of the turning roadway or corner radius. Design for storage is based on arrival rates and departure conditions; often, because right-turn lanes have higher capacities than left-turn lanes, the adjacent through lane volume will control the desirable length. (*23*)

Issues Specific to Intersections near Highway-Railroad Grade Crossings

There has not been a great deal of research specifically related to intersection channelization near highway-railroad grade crossings. However, despite the small number of specific studies related to the topic, there are some issues related to channelization in general that can be applied to conditions at or near grade crossings.

The proper use of islands is very important to the safe and efficient performance of an intersection near a highway-railroad grade crossing. One of the primary functions of a raised island is to prohibit movements that are forbidden and/or illegal. Corresponding to this function is the use of raised islands to confine vehicles from moving out of their lanes to drive around lowered gates at crossings. Raised islands used in this way should follow the guidelines stated earlier; that is, islands should not confuse the driver, should be large enough to be effective, should not be located in areas of restricted sight distance, and should be used with caution on rural approaches with high speeds.

The *Railroad-Highway Grade Crossing Handbook* provides more specific instructions for islands at grade crossings. It states that an engineering study should be conducted to determine if islands are appropriate; this study should consider accident history, driver response to lowered gates, train and vehicle volumes, detection systems in place, approach geometry, and the potential hazard of the island itself. Islands should extend far enough away from the crossing to accommodate queues and should not have cut-outs for access and egress of local traffic. The ends of the island should be protected as other traffic islands, to provide a maximum degree of warning of the presence of the island and a definite indication of the proper vehicle path or paths to be followed. (*3*)

Another use of islands is for placement of traffic control devices. On certain types of roadways, it is often productive to place signals or gate arms at both the right and left sides of the approach for improved visibility. Many times, this requires placement of these devices in a median island, which adds another element to the proper design of the island. The 2000 MUTCD (Section 8D.1) states that at least 0.6 m (2 ft) of horizontal clearance shall be provided from the face of the vertical curb to the closest part of the signal or gate arm in its upright position for a distance of 5.1 m (17 ft) above the roadway. (*1*)

Exclusive turning lanes are also useful for improved safety and efficiency at intersections near grade crossings. The use of left- and right-turn lanes can remove decelerating and queued vehicles from conflicting with through traffic in the same direction. This is especially important at high-speed rural locations and high-volume signalized locations. At high-speed locations, making provisions for turning vehicles reduces the potential for rear-end accidents by through vehicles. At high-volume locations, sufficient storage for turning vehicles improves level of service at the intersection and allows optimization of signal timings.

Using the guidelines stated by AASHTO and the *Intersection Channelization Design Guide*, an engineering study can determine if volumes, capacity, and other conditions are conducive to the installation of auxiliary turning lanes at intersections near highway-railroad grade crossings. As with any other geometric changes, consideration must be given to the space available at the intersection to ensure that lane lengths and widths are appropriate.

Conclusions

While there is not a great deal of specific information regarding channelization of intersections at or near highway-railroad grade crossings, there are relevant applications of principles and guidelines used for intersections in general. Two common types of channelization devices are islands and turning lanes; both can be used near grade crossings to improve safety and efficiency. Care must be taken to ensure that these devices are used properly; improper or excessive use of channelization can confuse drivers and increase the potential for accidents. However, with proper planning and use of the guidelines provided in the manuals and standards listed here, channelization devices can be used to increase level of service, improve coordination between rail and vehicle traffic, maximize convenience and capacity, and reduce accident severity at intersections near highway-railroad grade crossings.

CHAPTER 6

HIGH-PROFILE ("HUMP") CROSSINGS

When a long-wheelbase or low-ground-clearance vehicle negotiates a high-profile roadway, such as a highway-railroad grade crossing, roadway crown, or driveway entrance, the vehicle may become lodged or stuck on the "hump." A somewhat common occurrence is one in which a railroad is on an embankment and a low-ground-clearance vehicle on the crossing roadway becomes lodged on the track and is subsequently struck by a train. A set of standards or guidelines for the design of high-profile crossings could reduce these incidents and improve safety; however, guidelines currently in existence are often merely suggestions for desired design values and are either not made readily available to designers or are not practical for application. While there has been a great deal of discussion about the serious nature of the problem, literature on the subject is difficult to find. Other topics in highway-railroad grade crossing research are much more common, such as traffic control devices (passive and active), driver behavior and education, and legislation.

Existing Guidelines

There were two sets of guidelines for "hump" crossings found in this review: AASHTO and the American Railway Engineering Association (AREA). AREA's *Manual for Railway Engineering* (*24*) states that it is desirable that the surface of the highway be neither more than 75 mm (3 in) higher nor more than 150 mm (6 in) lower than the top of the nearest rail at a point 9 m (30 ft) from the rail, measured at a right angle thereto, unless track superelevation dictates otherwise.

AASHTO's *Policy on Geometric Design of Highways and Streets* (*4*) has guidelines similar to AREA, supplemented by comments and equations to suggest adequate sight distance for drivers. AASHTO states that it is desirable that the intersection of highway and railroad be made as level as possible from the standpoint of sight distance, rideability, and braking and acceleration distances. In some instances, the roadway vertical alignment may not meet acceptable geometrics for a given design speed because of restrictive topography or limitations of right-of-way. AASHTO guidelines state that “(a)cceptable geometrics necessary to prevent drivers of low-clearance vehicles from becoming caught on the tracks would provide the crossing surface at the same plane as the top of the rails for a distance of 0.6 m (2 ft) outside the rails. The surface of the highway should also not be more than 75 mm (3 in) higher or lower than the top of the nearest rail at a point 9 m (30 ft) from the rail unless track superelevation dictates otherwise. Vertical curves should be used to traverse from the highway grade to the level plane of the rails.” (*4*)

FHWA has a section on vertical alignment in their *Railroad-Highway Grade Crossing Handbook*; however, it does not contain any guidelines unique to FHWA. (*3*) It does contain a reference to the AREA guidelines, and it makes mention of some practices by specific states and railroad companies.

Background

There have been recent research efforts to further examine the effects of “hump” crossings and solutions for dealing with them. Following is a summary of selected projects.

Eck and Kang (1991)

In 1991, Eck and Kang (*25*) undertook a research project to determine the extent of the problem of “hang-ups” and accidents involving low-clearance vehicles at grade crossings. They also attempted to identify specific classes or categories of vehicles with low ground clearance, develop a computer model for checking whether a given class of vehicle could negotiate certain profiles, and develop design criteria for crossing profile alignments based on the problem classes of vehicles. In their research, Eck and Kang received comments from national, state, and local agencies indicating that the problem of low-clearance vehicles at grade crossings is a significant one. For example, the National Transportation Safety Board (NTSB) had investigated several serious accidents of this type and made recommendations relative to the problem. There was no indication, however, that the AREA or other guidelines had been used in the NTSB accidents.

Due to accidents in their respective states, the departments of transportation in Alabama, North Carolina, and Florida each developed measures to identify high-profile crossings and designed advance warning signs to post at those crossings. Because of the efforts in Florida, NTSB issued a safety recommendation to AASHTO, encouraging the adoption of the Florida plan or one that was comparable. They also issued a safety recommendation for advance warning signs for high-profile surfaces to address the issue in the MUTCD.

Because of the lack of data available concerning low-clearance vehicle incidents and characteristics, the researchers decided to collect data on such vehicles. Their intent was to estimate at least the potential magnitude of the problem by determining the types and quantities of low-clearance vehicles on particular highways. In addition to traffic counts, general classes of vehicles were categorized, and a detailed classification of trucks was made. The researchers also obtained literature from low-bed truck trailer manufacturers; this literature illustrated a wide variety in dimensions of low-clearance vehicles. The lowest published ground clearance was around 200 mm (8 in), but data collected in an earlier study showed clearances as low as 50 mm (2 in). Therefore, the researchers decided to collect additional wheelbase and ground-clearance data for this study.

Results of the vehicle classification counts indicated that trucks made up just over 13 percent of the traffic stream at the study site. Low-clearance trucks accounted for 0.8 percent of the traffic stream, or about 5.7 percent of all trucks. In addition, car-trailer and pickup-trailer combinations accounted for 1.1 percent of the traffic stream, resulting in about 2 percent of the total traffic stream being characterized as low-clearance vehicles. Analysis of wheelbase and ground-clearance data yielded no discernable relationship between the two; in addition, there seemed to be no significant difference in clearance between loaded and empty vehicles. During the collection of wheelbase and ground-clearance measurements, drivers were informally interviewed about their experiences; virtually every driver either had experienced a hang-up or knew a driver who had, confirming that the problem was widespread.

The researchers also desired to utilize computer technology to simulate the movement of trucks over grade crossings. They developed their own program, "HANGUP," which plots user-entered roadway profile data and graphically presents vehicle movement over the roadway. The program allows designers to determine sections of roadway where hang-up problems can occur with certain clearance/wheelbase combinations. This program was tested with data from several grade crossings to evaluate performance and output. The researchers are still making changes and improvements to the software but are satisfied that it can be used to help designers make decisions about potential problems and solutions at high-profile grade crossings. (*25*)

Eck and Kang (1993)

In 1993, Eck and Kang followed up on their 1991 study by applying the "HANGUP" software to the development of design standards to accommodate low-clearance vehicles. In this follow-up effort (*26*), Eck and Kang again indicated that, although researchers have been aware of vehicle ground-clearance problems for a number of years, efforts have been sporadic and directed at specific problems. Thus, there has been a lack of a concentrated effort to address the general problem of low-clearance vehicles.

The researchers first applied the "HANGUP" software to the AREA design standards. In doing so, they found that hang-ups would not occur for a large number of clearance/wheelbase combinations if the AREA standards were used. Specifically, hang-ups would occur only for 25 mm (1 in) clearance vehicles with wheelbases longer than 3.9 m (13 ft), for 50 mm (2 in) clearance vehicles with wheelbases longer than 7.3 m (24 ft), and for 75 mm (3 in) clearance vehicles with wheelbases longer than 10.0 m (33 ft).

In order to have a consistent basis for evaluation, the researchers defined a design vehicle for use in this study. They selected a vehicle with a ground clearance of 125 mm (5 in) and a wheelbase of 11.0 m (36 ft), based on the 85th percentile values of previously observed vehicles. Based on this design vehicle, researchers developed a set of maximum safe grades and curve lengths for high-profile crossings. Further, they developed a list of considerations involved in the design of crest vertical curves for low-profile vehicles:

- To eliminate hang-up incidents at high-profile roadways, the rate of change of grade should be constant (a parabolic curve).

- All interstate and primary highways should accommodate the design low-ground-clearance vehicle.
- All secondary highways and local roads that cannot meet the design standard should provide an advance warning sign advising of the potential clearance problem.
- A detour route or turning space on a relatively level area, which does not interrupt through traffic, must also be provided for low-clearance vehicles in advance of the crossing.
- Weigh stations should measure wheelbase and ground clearance under static conditions for vehicles whose ability to negotiate high-profile roadways appears questionable.
- On existing roadway profiles, surface maintenance is very important. Pavement patches or pavement defects can lead to hang-ups.

The researchers also encouraged inclusion of ground clearance measurements as a part of the current permitting process for oversized vehicles and consideration of establishing minimum ground-clearance standards for vehicles operating on public highways.

In the discussion of the researchers' findings and conclusions, Gattis mentions a couple of additional points to consider. (*26*) First, he notes that researchers and designers should be aware of the tolerances that are possible when field crews actually construct or repair a roadway. Second, he suggests that while the idea of a design vehicle is good, there are ways to determine design values other than the 85th percentile. He suggests examining the distribution of ground clearances and evaluating the consequences of not accommodating a certain percentage of values. Finally, he concurs with the suggestion that perhaps minimum values for ground clearance and/or maximum values for wheelbase should be established for vehicles on public highways; if these values are set, it allows engineers to determine a design vehicle with a more logical basis than current circumstances would allow.

In the researchers' closing response to Gattis' discussion, they concur with his remarks and add that considerable work still needs to be done before design criteria for low-clearance vehicles becomes a formal part of design policy. (*26*)

Conclusions

The issue of high-profile "hump" crossings seems to be an issue that affects many in transportation, both in highway concerns and in railroad concerns. However, there is a lack of any definitive standards to reduce or eliminate the hazardous effects of "hump" crossings. In addition, while there have been studies to address specific problems, there is not a large body of research dedicated to a general solution to low-clearance vehicles at high-profile crossings. Current practice seems to be that each crossing is dealt with on an individual basis; if a pattern of hang-ups develops, then improvements are considered for that crossing. In many cases, this pattern is verified by simply examining the pavement near the tracks for gouge marks; if there are marks, then there is probably a problem that needs to be addressed. Otherwise, improvements are seldom suggested or implemented. There is also the possibility that as improvements are made and railroad companies re-ballast the tracks, the surface of the tracks can migrate upwards over time, increasing the risk of hang-ups.

Given the wide range of clearances and wheelbases found on vehicles in use on public highways, it is difficult to define meaningful standards that will cover the majority of vehicles and still be practical to implement. It would be impossible to design for every conceivable clearance/wheelbase combination, yet it is also difficult to determine which combinations should be emphasized and which should be discounted. The importance of those combinations could change over time or in a different location or region. Perhaps the establishment of minimum ground clearance or maximum wheelbase values is the solution; this would provide designers with a target for future standards and guidelines. Regardless of which suggestions are implemented in the future, there still remains a great deal of work and research to be done in order to properly address the problem of "hump" crossings and reduce their hazardous effects.

CHAPTER 7

ILLUMINATION

The use of lighting on streets or highways is dependent on a number of design decisions and goals, but is generally intended to improve the visibility provided on the facility. (*27*) In recent years there has been a great deal of interest in illumination of streets and highways. One of the principal objectives of illumination is to achieve a reduction in night accidents. There have been several published papers on street and highway lighting reporting the results of several years of research on this subject. Standards and guidelines for street and highway lighting are well established. However, there have been only a limited number of research projects that addressed the illumination of rail-highway grade crossings. (*28*)

Background

The installation of roadway lighting at rural intersections can potentially reduce the higher levels of hazard at these locations. The highway engineer, however, must weigh the benefit of lighting against other intersection safety improvements such as channelization, delineation, signalization, or geometric changes. To make such decisions, the engineer should know the possible benefits to be gained from the installation of lighting. (*29*)

A wide number of interests are served by providing roadway illumination, although the purposes may vary by facility type and location: (*27*)

- view the roadway,
- view roadway appurtenances,
- view other traffic,
- improve driver and pedestrian visibility,
- deter crime,
- promote commercial interests and areas, and/or
- enhance community pride.

Implicit in several of these purposes is the goal of improving safety. Illumination is frequently provided to enhance safety on facilities, with generally good results.

Transient visual adaptation (TVA) is a potential problem that can occur downstream of illuminated areas. Because of the visual adaptation of the driver's eyes to the more brightly lit area, the distance between initial perception of objects is reduced in the darker areas downstream. TVA effects have been measured for areas illuminated from one to four luminaires, and could reasonably be suspected in situations where railroad grade crossings are on cross streets that intersect illuminated roadways. Illumination designs should consider these unintended effects resulting from illumination on roadways, providing countermeasures where necessary. Lighting a grade crossing can be a low-cost safety improvement strategy. It is a strategy that is not intended to replace other warning devices but to reduce night accidents at crossings where the lack of train visibility appears to be a problem. (*28*)

Night Visibility

The logical starting point for any discussion of lighting is the eye. An intelligent lighting design must be based on an understanding of what the eye can and cannot do. (*30*)

The ideal seeing conditions exist when the whole field of view is as uniform in brightness as possible, but vision is limited even then. When viewing a bright field some of the light entering the eye is reflected, causing stray light within the eye. The effect of stray light in the eye is to superimpose a veiling brightness upon the object viewed and decrease the brightness contrast needed for discernment. For non-uniform light in the field of view the stray light in the eye increases, and the veiling brightness is directly proportional to the intensity of the glare source. For non-uniform fields of view, as found in roadway lighting with large glare sources present, the stray light produces disability veiling brightness (DVB), which can adversely influence visibility and must be taken into consideration when evaluating roadway lighting systems. Lighting systems are often described by quantitative terms such as foot-candles, pavement brightness, and average lighting intensity. Therefore, a lighting system is often judged by the quantity of light on the pavement. However, visibility is the important criterion, and to fully evaluate a lighting system, other measures such as the DVB of each system must be measured or calculated. (*31*)

Dark adaptation may be considered as the most important element regarding DVB. This process, which becomes less efficient with age, allows a viewer to take maximum advantage of decreasing amounts of light. It is affected by two types of eye cells, namely, the cones and the rods. Cone cells function best under high levels of illumination, whereas rod cells are more efficient under low levels (cone cells are also proficient in color and form perception). If the eye is deprived of light, cone cells adapt to the loss in 5 to 10 minutes, after which time the rod cells take over the light-sensing function and adapt to low levels of illumination in 30 to 50 minutes. Because most persons function at frequently changing levels that exist somewhere between very high and very low illumination, the level of adaptation must also change to accommodate visual efficiency to the changing levels of illumination. Going from darkness into light, the eye adapts itself much faster than when going from light into darkness. The temporary loss of vision due to the sudden change in level of illumination is thus more of a problem on the exit side of a rural intersection. (*30*)

Influence of Illumination on Railroad-Highway Grade Crossings

Driving at night is more difficult than driving during the day. Although lack of visibility is not the only difference between the two situations, it certainly is a major difference, and there is much literature on street and highway lighting. Standards and guidelines for street and highway lighting are well established. However, there has been very little research concerning the illumination of railroad-highway grade crossings. (*32*)

When illumination is used at rail-highway grade crossings, it is usually an extension of the street lighting, and there are no universally accepted standards. Street lighting standards are primarily concerned with minimum levels of uniform light on the street surface. When a train is crossing a street or highway at night, the important variable is the amount of light on the vertical surface of the rail cars. There are no standards that address this. (*28*)

The standard for transition lighting is presented in “American National Standard Practices for Roadway Lighting.” It is good practice to gradually decrease brightness in the driver’s field of view when emerging from a lighted section of roadway. This may be accomplished by extending the lighting system in each exit direction using approximately the same spacing and mounting height but graduating the size of the lamp. A recommended procedure is to utilize the design value for the roadway as the calculation base. Using the design speed of the roadway, the reduced lighting-level sectors should be illuminated for a five-second continuous exposure to the sector illumination level of one-half of the preceding higher lighted sector, but the average illumination in the terminal sector should not be less than 2.7 lux (0.25 foot-candle) nor more than 5.5 lux (0.5 foot-candle). (*33*)

Accidents at Railroad-Highway Grade Crossings

All the accident data for U.S. railroad-highway grade crossings were analyzed for 1967-1974; the results are listed in Table 2.

Table 2. Railroad-Highway Grade Crossing Accidents in the U.S., 1967-1974.

Type of Accident	No. of Accidents		
	Day	Night	Day and Night
Vehicle hits train	3870	4637	8507
Train hits vehicle	12,997	5479	18,476
Total	16,867	10,116	26,983

When a vehicle hits a train during the day, 86 percent hit the lead unit, and only 14 percent hit one of the remaining cars in the train. However, in 54 percent of the accidents at night, the vehicle hits the lead unit, and in 46 percent of the accidents, it hits one of the remaining cars. Due to the slow speeds involved, only the immediate vicinity of the crossing needs to be lighted. Therefore, accidents are a visibility problem and not a speed problem. (*32*)

Of grade-crossing accidents, 37 percent occur at night; of this 37 percent, 47 percent are accidents in which a vehicle runs into the side of a train. A rough estimate of the benefit of illumination is a 30 percent reduction in night accidents at crossings. (*32*)

Illumination Survey

In a study by Russell and Konz (28), a questionnaire was mailed to 50 states, 45 Class I railroads, and 306 city and county traffic engineers. Replies were received from 43 (86 percent) states, 20 (44 percent) railroads, and 199 (36 percent) city/county traffic engineers. The main conclusion from this portion of the study is that there are neither accepted standards nor uniform practices on any aspect of rail-highway grade crossing illumination. (*28*)

Illumination Testing at Grade Crossings

In tests by Russell and Konz (*28*), a number of important findings were developed:

- In general, lights on the far side of the train are relatively useless. That is, the light must illuminate the target, not silhouette it. This, in turn, means that one light at a crossing is not satisfactory unless it is on a one-way street.
- Four lights per crossing are preferred by the subjects over two lights per crossing, but this could be a question of the amount of light on the target rather than the distribution of light.
- Due to the low reflectivity of boxcars and thus the low luminance, there seems to be a need for a minimum of 20 vertical lux (1.9 ft-candles) on the boxcar side. More than 40 vertical lux (3.7 ft-candles) appears to give only little additional improvement.
- A distinctive color such as that of the high-pressure sodium lamp appears to be worthwhile.

Warrant for Rural At-Grade Intersection Illumination

One possible solution to the establishment of illumination guidelines is to develop warrants for their consistent use.

Warrant Development Concept

In considering warrants, there are two basic questions that must be addressed. The first pertains to the feasibility of fixed illumination as a solution to rural intersection problems; the second is related to the feasibility of fixed illumination as a solution compared to other design alternatives. These two questions reflect quite diverse views on design and decision-making. In the first case, roadway lighting decisions are made on the merits of lighting alone, and lighting programs are somewhat independent of other design improvements at intersections. (*30*)

The latter question requires the designer to deal with the broader problem in which illumination is one of the design elements that may be considered. Because it is possible that one or more of the design elements can satisfy the same objective, an analysis of the trade-offs between the components is necessary to achieve a final design solution. (*30*)

These two questions are clearly related to budgeting decisions. The first reflects the fact that lighting projects are funded on their own merits, and funds are available specifically for that purpose. The second indicates that a general allocation is made for roadway improvements, and the designer will attempt to best achieve the objective with the available resources. (*30*)

Warrants for rural intersection illumination were developed, which are based on the ratio of night accidents to total accidents. The ratio serves to indicate the intersections at which accidents can be associated with the need for fixed illumination. (*30*)

Development of a Predictor for Warrant Determination (30,34)

In order to determine which intersections warrant lighting and priorities for lighting installations, the effect of lighting on accidents should be ascertained. Wortman et al. found that the most reliable accident measurement variable was the night-to-total accident ratio. (*34*) This measure has the practical advantage that knowledge of the night traffic volume is not required. Table 3 provides an illustration of this measure.

Table 3. Mean Night Accident to Total Accident Ratios. (34)

Illumination	Mean Night Accident/ Total Accident	Standard Deviation	Significant Level
Yes	0.25	0.17	0.08
No	0.33	0.14	

The final predictor involves the use of the night-to-total ratio, which shows that illumination reduces night accidents in proportion to total accidents:

$$\text{Predicted Accident Reduction} = N_p - N_f = N_p - D/3$$

Where:

N_p = present night accidents before lighting

N_f = final night accidents after lighting

D = day accidents (before and after lighting)

The use of the reduction in night accidents as the criterion yields a predictor by which priority values can be generated for each intersection. The intersections with the highest priorities are those with the highest values of accident reduction.

Potential Lighting Warrants and Recommendations (27,29,30,34)

A number of potential warrants and recommendations have been developed that provide indications regarding when illumination should be provided at intersections:

- Rural intersections should be considered for lighting if the average number of nighttime accidents (N) per year exceeds the average number of day accidents (D) per year divided by three.
- Illumination should be provided whenever an intersection is channelized.
- The lighting program should be based on the resulting list of intersections ranked in priority order by mean of the benefit/cost ratio (expressed as annual reduction in accidents/annual cost).
- The lighting program should be reviewed at regular intervals, as additional accident data become available.
- It has been implicitly assumed that the highway improvement budget will be limited and thus, interest will be focused on maximizing the benefits of a limited budget. For this reason, reductions in number of accidents rather than accident rate have been used.
- The benefits of illumination, in terms of accident reduction, can be predicted. Accident reduction was found to be the most feasible criteria for evaluating the benefit of illumination.
- An estimate of the average number of accidents saved per year by installing lighting at previously unlit intersections can be obtained by subtracting one third of the average number of day accidents per year from the average number of night accidents per year that occurred prior to the installation of illumination.
- In order to obtain the maximum benefits from a limited illumination budget, the cost of lighting each particular intersection should be determined and included in the criteria for establishing priorities. The simplest method of doing this is to use a benefit-cost ratio as the criteria for ranking.

Influence of Lighting based on Average Daily Traffic (ADT)

To identify ADT levels that might respond most favorably to lighting, Walker and Roberts ran an analysis of variance by using the number of night accidents as the dependent variable. Two levels of lighting, light and no light, were used. Six ADT levels were selected in such a way that each group contained approximately the same number of observations. They found that until traffic volumes reached 3500 vehicles/day, little effect was noted. Between 3500 and 5699, however, the installation of lighting produced a significant reduction in the number of night accidents. (*35*)

Conclusions

Some railroad-highway grade crossings are likely to experience safety and operational problems at night that illumination might ameliorate. The general literature on highway illumination plus the studies available on railroad-highway crossings indicate that illumination is an effective strategy. (28)

Crossing illumination has generally been accepted with enthusiasm by local citizens and some public road authorities. Illumination provides an opportunity to improve safety at crossings that might otherwise not be addressed. Illumination may provide an effective low-cost alternative for improving nighttime crossing safety in many instances, although illumination is not appropriate for all situations and will not address some types of safety concerns.

The provision of lighting at railroad-highway crossings should be strongly considered at locations where nighttime accidents are over-represented or where there is a pattern of vehicles hitting the side of trains. The illumination provided should focus on illuminating the side of the trains rather than vertically oriented street lighting. Engineers should also be sensitive to the provision of appropriate lighting transitions, particularly where there is a gap in the roadway lighting at a railroad-highway crossing on an otherwise lighted roadway or, similarly, an abrupt end to the lighting immediately prior to the crossing.

CHAPTER 8

RECOMMENDED CHANGES TO THE ROADWAY DESIGN MANUAL

The *Roadway Design Manual* (*40*) currently has few references to railroad grade crossings and provides little in the way of direct guidance for their design. In general, the manual contains information related to required design practices and methods with only a limited amount of information related to background issues and "how-to" information. This limitation provides a manual that does not unnecessarily replicate other guidelines such as the *Green Book* (*4*).

The nature of the recommended guidelines for railroad grade crossings near at-grade highway intersections prepared in this project is in the form of information provided to assist the designer in preparing a design rather than in providing required design controls and criteria.

Researchers working on TxDOT projects recently prepared a number of sets of guidelines, but a method for providing them is largely lacking other than through printed documents. Given the department's philosophy of providing manuals in an on-line format to facilitate distribution and change, this appears to provide an opportunity to disseminate these guidelines. Accordingly, it is recommended that the guidelines be provided to designers and engineers through the use of an on-line document available through links located in the Roadway Design Manual.

The links should be provided in a separate chapter entitled "Design Guidelines" (or similar descriptive wording). A disclaimer should be provided to inform the designer that the material referenced is not a part of the manual but rather additional information that can help guide him or her in the preparation of the roadway design.

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APPENDIX

SURVEY TEXT

Geometric Design Guidelines for At-Grade Intersections
Near Railroad-Highway Grade Crossings
for Texas Department of Transportation Project 0-1845

We need your help in identifying design strategies that are being used at at-grade highway intersections near railroad grade crossings. Please contact Mark Wooldridge at (979) 845-7321 if you would like further information regarding the survey or have any questions regarding this project.

THANK YOU FOR YOUR INPUT

We may contact you at a later date by telephone or in person (by appointment) to clarify your responses or to get additional information about a design condition or treatment that you described.

Please indicate if you would especially like for us to contact you: ____

Name ____

Title ____

Agency ____

Address ____

____

____

Phone ____

Fax ____

E-mail ____

Please mail or fax surveys to:

Mark D. Wooldridge, P.E.
Texas Transportation Institute
College Station, TX 77843-3135
Phone: (979) 845-9902
Fax: (979) 845-6481
E-mail: mwooldridge@tamu.edu

SURVEY QUESTIONS FOR HIGHWAY/STREET DESIGNERS OR ENGINEERS

(All questions assume that a railroad grade crossing is within 200 ft of the at-grade roadway intersection.)

<table>
<tr><td colspan="3">1. The following questions pertain to general design considerations for at-grade roadway intersections near railroad grade crossings.</td></tr>
<tr><td>1a. Please estimate the percentage of grade crossings in your district within 200 ft of an at-grade intersection. [Note: Districts may already have this information as a result of the preemption survey conducted in 1996 and 1997.]</td><td>Urban
Active ____
Passive ____</td><td>Rural
Active ____
Passive ____</td></tr>
<tr><td>1b. What design vehicle do you use for designing at-grade intersections near railroad grade crossings?</td><td>Primary Design Vehicle
Passenger Car ____
Single Unit Truck ____
School Bus ____
Tractor/Trailer ____
Other:_______________</td><td>Secondary Design Vehicle
Passenger Car ____
Single Unit Truck ____
School Bus ____
Tractor/Trailer ____
Other: _______________</td></tr>
<tr><td>1c. When do you consider the use of secondary design vehicle?</td><td>Locations

Never ____
Urban ____
Suburban ____
School Zone ____
Rural ____</td><td>

High speed ____
Low speed ____
Hilly ____
Flat ____
Other: _______________</td></tr>
<tr><td>1d. For newly designed or redesigned intersections, do you give special consideration to the approach grades to the railroad grade crossing?</td><td colspan="2">No ____
Yes ____
If yes, how have you addressed the problem?</td></tr>
<tr><td>1e. When widening roadways toward parallel railroad tracks, have you had a problem with the creation of “hump” crossings on intersecting roadways? (A hump crossing is a high profile crossing where the railroad tracks may potentially impact long truck trailers with low ground clearances).</td><td>Urban
No ____
Yes ____
If yes, please describe the circumstances:</td><td>Rural
No ____
Yes ____
If yes, please describe the circumstances:</td></tr>
</table>

1f. If you have had problems due to the presence of "hump" crossings, please describe the problem, what actions were taken, and how the crossings were improved (if applicable).	No problems ____ Problems and solutions:	
1g. Do you illuminate the railroad grade crossing if the nearby at-grade roadway intersection is illuminated?	*Urban* Always ____ Never ____ Sometimes ____ If sometimes, when?	*Rural* Always ____ Never ____ Sometimes ____ If sometimes, when?
1h. Do you illuminate the nearby at-grade roadway intersection if the railroad grade crossing is illuminated?	*Urban* Always ____ Never ____ Sometimes ____ If sometimes, when?	*Rural* Always ____ Never ____ Sometimes ____ If sometimes, when?

<table>
<tr><td>1i. Do you illuminate railroad grade crossings if there is no nearby roadway intersection?</td><td>Urban
Always ____
Never ____
Sometimes ____
If sometimes, when?</td><td>Rural
Always ____
Never ____
Sometimes ____
If sometimes, when?</td></tr>
<tr><td colspan="3">2. The following questions pertain to auxiliary lanes on the roadway that parallels the railroad tracks (an operations goal sometimes is to not block through traffic on this parallel roadway).</td></tr>
<tr><td>2a. Do you provide turn lanes for traffic turning right toward the railroad tracks?</td><td>Urban 2-lane
Never ____
Always ____
Sometimes ____
If sometimes, when?

Urban Multilane
Never ____
Always ____
Sometimes ____
If sometimes, when?</td><td>Rural 2-lane
Never ____
Always ____
Sometimes ____
If sometimes, when?

Rural Multilane
Never ____
Always ____
Sometimes ____
If sometimes, when?</td></tr>
<tr><td>2b. Do you provide turn lanes for traffic turning left toward the railroad tracks?</td><td>Urban 2-lane
Never ____
Always ____
Sometimes ____
If sometimes, when?

Urban Multilane
Never ____
Always ____
Sometimes ____
If sometimes, when?</td><td>Rural 2-lane
Never ____
Always ____
Sometimes ____
If sometimes, when?

Rural Multilane
Never ____
Always ____
Sometimes ____
If sometimes, when?</td></tr>
</table>

2c. Does the presence of the nearby grade crossing affect the lane layout or provision of auxiliary lanes on the roadway that is parallel to the railroad tracks in some other manner?	*Urban 2-lane* Never ____ Always ____ Sometimes ____ If sometimes, when? ____ *Urban Multilane* Never ____ Always ____ Sometimes ____ If sometimes, when? ____	*Rural 2-lane* Never ____ Always ____ Sometimes ____ If sometimes, when? ____ *Rural Multilane* Never ____ Always ____ Sometimes ____ If sometimes, when? ____
3. The following questions pertain to auxiliary lanes on the roadway that ***intersects the railroad tracks***.		
3a. Does the presence of the railroad grade crossing affect the layout of right turn lanes?	*Urban 2-lane* Never ____ Always ____ Sometimes ____ How? *Urban Multilane* Never ____ Always ____ Sometimes ____ How?	*Rural 2-lane* Never ____ Always ____ Sometimes ____ How? *Rural Multilane* Never ____ Always ____ Sometimes ____ How?

3b. Does the presence of the railroad grade crossing affect the layout of left-turn lanes?	*Urban 2-lane* Never ____ Always ____ Sometimes ____ How? *Urban Multilane* Never ____ Always ____ Sometimes ____ How?	*Rural 2-lane* Never ____ Always ____ Sometimes ____ How? *Rural Multilane* Never ____ Always ____ Sometimes ____ How?
3c. Does the presence of the nearby grade crossing affect the lane layout or provision of auxiliary lanes on the roadway that intersects the railroad tracks in some other manner?	*Urban 2-lane* Never ____ Always ____ Sometimes ____ How? *Urban Multilane* Never ____ Always ____ Sometimes ____ How?	*Rural 2-lane* Never ____ Always ____ Sometimes ____ How? *Rural Multilane* Never ____ Always ____ Sometimes ____ How?

4a. Do you provide additional signs or markings on the roadway ***parallel to the railroad tracks*** <u>because</u> of the closeness of the grade crossing to the at-grade intersection?

Sign or Marking	*Always*	*Never*	*Sometimes Provided (please list reason)*
RR advance warning (highway parallel to railroad) (W10-2, -3, or -4)	____	____	____________________
No right turn (R3-1a)	____	____	____________________
No left turn (R3-2a)	____	____	____________________
Stop here on red (R10-6)	____	____	____________________
Do not stop on tracks (R8-8)	____	____	____________________
Other:	____	____	____________________

4b. Do you provide additional signs or markings on the roadway ***intersecting the railroad tracks*** <u>because</u> of the closeness of the grade crossing to the at-grade intersection?

Sign or Marking	*Always*	*Never*	*Sometimes Provided (please list reason)*
No right turn (R3-1a)	____	____	____________________
No left turn (R3-2a)	____	____	____________________
Stop here on red (R10-6)	____	____	____________________
Do not stop on tracks (R8-8)	____	____	____________________
Stop ahead (W3-1a)	____	____	____________________
Signal ahead (W3-3)	____	____	____________________
Other:	____	____	____________________

5. Are there locations where you prohibit vehicles stopping between the grade crossing and the parallel roadway?	*Urban*	*Rural*
	No ____ Yes ____ If yes, what is the minimum clearance space? If yes, what are the signs or markings used to establish the prohibition?	No ____ Yes ____ If yes, what is the minimum clearance space? If yes, what are the signs or markings used to establish the prohibition?

<table>
<tr><td>6.</td><td>Some safety devices placed at railroad grade crossings have limitations that require modifications to allow their installation at certain locations (e.g., limits on gate length and configuration may require that islands be constructed, etc.). When in the design process are these limitations considered?</td><td>Preliminary design ____
Right-of-way determination ____
Detailed plan preparation ____
Never ____
Other (please explain):</td></tr>
<tr><td>7.</td><td colspan="2">Could you identify some potential study sites in your district (i.e., railroad grade crossings with nearby at-grade roadway intersections)? Please attach additional sheets if necessary.
Location 1
City/county:
Parallel highway:
Intersecting highway:
Crossing ID number:

Location 2
City/county:
Parallel highway:
Intersecting highway:
Crossing ID number:</td></tr>
</table>

8. What guidelines or procedures do you use when designing at-grade intersections near grade crossings? What additional guidance do you feel is needed for the design of at-grade intersections near railroad grade crossings (please attach additional sheets if necessary)?