Guidelines for the Use of Selected Active Traffic Control Devices at Railroad-Highway Grade Crossings

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Guidelines for selecting and installing active traffic control devices are beneficial to the practicing engineer who has responsibility for field installation and operation. This paper reports on a portion of the field installation and evaluation of two active traffic control devices for use at railroad-highway grade crossings. As a result, guidelines were developed for the use of a four-quadrant gate system and a highway traffic signal system for use at selected railroad-highway grade crossings. The characteristics of crossings that would be conducive to the use of a four-quadrant gate system and a highway traffic signal system were defined, with the objective of improving safety for the traveling public at the crossings. A four-quadrant gate system should be viewed as being between a standard gate system and a grade-separated crossing in terms of providing a level of safety to the traveling public. There are railroad-highway grade crossings that would not be economically feasible to grade separate, but a four-quadrant gate system would be cost-effective. Similarly, there are specific types of crossings that would receive a higher level of safety with the use of a highway traffic signal system and the upgrade would be cost-effective. The guidelines presented address the characteristics of the different types of crossings that would be appropriately served by these two active traffic control systems.

Historically, the engineering profession has assembled information that can be used to guide engineers in the deployment of traffic control devices for use on the highway system. These guidelines have aided the practicing engineer in selecting a particular type of device for a particular application. In addition, warrants are often developed that specify the conditions under which a particular type of device should be used. As an example, the *Manual on Uniform Traffic Control Devices* (MUTCD) provides both guidelines for certain types of devices such as overhead red-flashing beacons and warrants for such devices as stop signs (*1*). Although engineering judgment is essential for the selection and placement of any traffic control device, guidelines and warrants tend to aid an engineer in making a decision as to the type of device that should be used for a given situation. It is with the concept of providing guidance to the practicing engineer that guidelines have been developed for selecting traffic control devices at railroad-highway grade crossings.

Recognizing the need to fully address the issues and problems concerning warning devices at railroad-highway grade crossings, FHWA sponsored research to identify and evaluate innovative, active warning devices with potential for improving safety at these crossings. Through the research, innovative, active devices for use at railroad-highway grade crossings were identified and prototypes developed. The most promising active devices were evaluated in a detailed laboratory study (*2*), and the two devices chosen for field evaluation were

1. Four-quadrant gates with skirts and flashing light signals (see Figure 1), and
2. Highway traffic signals with white bar strobes in all red lenses (see Figure 2).

The field studies assessed the effects of these two traffic control devices on driver behavior and safety at typical grade crossings. In addition, other considerations important to the success and acceptance of these devices for general field use at railroad-highway grade crossings include hardware, installation, system operation, maintenance, and system power requirements.

From the field evaluation, these two devices proved to be technically feasible and practical, and were accepted and understood by the driving public. The cost effectiveness was shown to be extremely favorable for improving safety for motorists (*3–5*). Guidelines were developed for use of these two devices under various field conditions, to aid the practicing engineer in proper use of the devices as well as giving direction as to the conditions under which the two devices would be most cost effective.

According to the Federal Railroad Administration, during the period from 1977 through 1986, injuries and fatalities resulting from motor vehicle accidents at railroad-highway grade crossings decreased from 4,452 and 846 to 2,227 and 507, respectively. Much of this safety improvement may be attributed to the availability of federal funds for grade crossing improvement projects (*6*). The majority of this funding was used to upgrade passive crossings to active ones and has resulted in over one in four of the 192,454 public grade crossings being equipped with active warning devices. In 1986, there were 22,066 crossings (11.5 percent) equipped with automatic gates and 32,778 crossings (17.0 percent) equipped with flashing light signals (*7*).

Even with these improvements, over 50 percent of all car-train accidents in 1986 occurred at crossings with active warning devices, which represent only 28.5 percent of the total crossings (*7*). Thus, active crossings are overrepresented in

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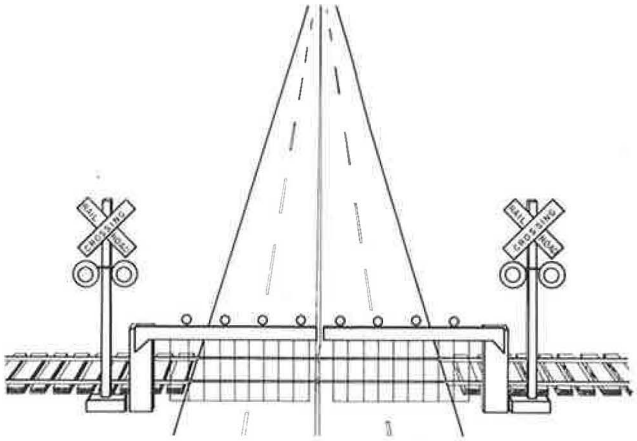

FIGURE 1 Four-quadrant gate system for field testing.

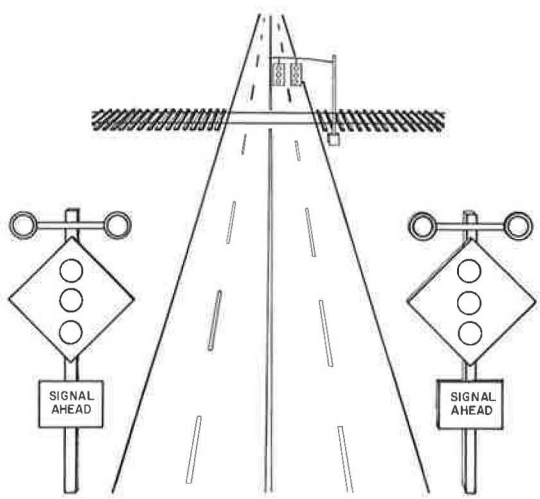

FIGURE 2 Highway traffic signal system for field testing.

terms of number of accidents. Although this apparently high number of accidents may be a result of higher vehicle and train volumes or more complex railroad-highway geometrics at active crossings, it is likely that some of the accidents are caused by motorists either not seeing or not understanding the active warning devices now used (*8*, *9*). Therefore, it seems that active traffic control devices used at crossings can be improved.

The following discussion outlines some of the results from the field testing and the considerations that should be given in choosing the locations for the use of the two devices: the four-quadrant gate system and the highway traffic signal system. These two active traffic control systems are designed to overcome some of the limitations of the existing active traffic control systems used at railroad-highway grade crossings.

FOUR-QUADRANT GATES WITH SKIRTS

The most effective device, in terms of driver response and safety, was the four-quadrant gate with skirts system (*3*, *4*). Based on the field test results (see Figure 3), the four-quadrant gate system outperformed the standard two-quadrant gate system on several key measures and proved to be operationally acceptable under a variety of conditions. This system substantially increased the safety of the crossing compared with the standard two-quadrant gate system based on the evaluation of the measures of effectiveness (MOEs). With the two-quadrant gate system, one or more motor vehicles drove around the closed gates during 84 out of every 100 train arrivals. The four-quadrant gate system reduced the number of gate violations (number of vehicles crossing) from an average of 260 per 100 train arrivals to 0. The four-quadrant gate system also reduced the CL20s (vehicles crossing less than 20 sec before arrival of train) from 60 per 100 train arrivals to 0, and reduced the CL10s (vehicles crossing less than 10 sec before arrival of a train) from 5 per 100 trains to 0.

The four-quadrant gate system did not significantly affect perception-brake reaction time (PBRT) or maximum deceleration levels at the test crossing. During the entire time that the system was in place, no motorists were trapped on the tracks. The system did not appear to increase the risk that a vehicle would be trapped on the tracks, provided the lowering of the far side gate arms was delayed by a few seconds to allow vehicle clearance. The four-quadrant gate system also did not interfere in any way with emergency vehicle operations at the test crossing during the field evaluation. (This would only be a problem for emergency vehicles if the equipment malfunctioned, and, at that point, the vehicle could break the gate arms if the situation warranted.)

In addition to the obvious safety benefits, four-quadrant gates with skirts are relatively easy to install, maintain, and operate, and they are reliable and durable. Worldwide experience with this gate system has been good.

The gates with skirts shown in Figure 3 may be considered a level of traffic control between standard two-quadrant gates and a grade-separated crossing. If standard two-quadrant gates do not provide the level of safety desired and a full grade separation is not economically attractive, then the four-quadrant gates with skirts should be the more cost-effective alternative.

Applications

Obviously, four-quadrant gates are very appropriate for those crossings that tend to have gate arm violations by motorists; the four-quadrant gates with skirts simply stop all violations by blocking the driving range around a gate arm. However, these gates can be used at any crossing where standard two-quadrant gates are warranted. Several types of crossings tend to have a large number of motorists driving around gate arms after they have been lowered. These crossings have certain unique characteristics that tend to result in violations and would be prime candidates for use of four-quadrant gates with skirts.

The characteristics of crossings listed below are good candidates for four-quadrant gates with skirts:

- Crossings on four-lane undivided roadways;
- Crossings with two or more tracks separated by a distance equal to or greater than the storage requirements for one or more motor vehicles;

FIGURE 3 Four-quadrant gate system installed at Cherry Street crossing in Knoxville, Tennessee.

- Crossings with large variations in train speeds and without constant warning time;
- Crossings for which motor vehicle-train collisions pose large potential safety problems such as
  - (a) crossings with large numbers of hazardous materials trucks or trains carrying hazardous materials,
  - (b) crossings with large numbers of school buses, and
  - (c) crossings with high-speed passenger trains;
- Crossings with continuing accident occurrences; and
- Crossings with consistent gate arm violations.

Crossings with the listed characteristics are candidates for the use of four-quadrant gates with skirts, because motorists often desire to drive around gate arms at these crossings, or if an accident does occur, the consequences can be very severe. The four-quadrant gate system tends to indicate to a driver that the crossing is dangerous and that more than normal caution should be exercised. The following discussion reviews the rationale for each type of crossing as a candidate for four-quadrant gates with skirts.

FIGURE 4 Four-lane, undivided roadway crossing.

Crossings on Four-Lane Undivided Roadways

Although several characteristics of crossings tend to result in violations by motorists desiring to drive around the gate arms, crossing geometrics play an important role in permitting or creating a decision to violate gate arms. With crossings on four-lane undivided roadways, there is a sufficient amount of lateral space to permit a motor vehicle to go around a gate arm that only covers two of the four lanes (see Figure 4). If there is sufficient space for maneuvering a motor vehicle around a gate arm with relative ease, some motorists will violate a gate arm, particularly if the driver perceives a long waiting time before the arrival of a train.

Crossings with Two or More Tracks a Substantial Distance Apart

Crossings that have two or more tracks separated by a distance equal to or greater than the storage requirements for one or more motor vehicles result in some gate arm violations. A truck driving around a gate arm for multiple tracks separated by a substantial distance is shown in Figure 5. Field observations indicate that motorists will often pull around one gate arm and use the lateral space between the tracks to reassess whether there are other trains coming on the set of tracks they are now approaching. More violations are expected as the spacing between the tracks increases.

Crossings with Large Variations in Train Speeds and Without Constant Warning Time

There are crossings that have a large variation in train speeds, from slow-moving freight trains of 20 mph or less to high-speed passenger trains of 80 mph or more. When predictors are not used, obviously there is a substantial difference in the length of time that gate arms are down for the approaching

FIGURE 5 Tracks separated by sufficient distance to store motor vehicles.

FIGURE 6 Hazardous materials truck using crossing.

trains. Field observations seem to indicate that, in these types of situations, drivers have difficulty recognizing these varying speeds, i.e., if a driver frequently encounters a gate arm down for a long period of time at a crossing, he has a tendency not to wait for a long activation and will often drive around. Obviously, with fast-moving trains, this creates a severe safety hazard.

Crossings for Which Motor Vehicle-Train Collisions Pose Large Potential Safety Problems

There are crossings where the type of motor vehicles that use it create a potential for severe safety problems should a collision occur between a train and a motor vehicle. Additional safety measures are often necessary to minimize the potential for conflicts at these crossings. Four-quadrant gates with skirts could significantly improve safety at these crossings.

Hazardous Materials Trucks Hazardous materials trucks can pose a serious problem should a collision occur between one of those vehicles and a train as shown in Figure 6. There have been some very serious accidents of this nature in the United States in the last few years. Some of these resulted when gasoline tankers were driven around gate arms. The results were disastrous. Figure 7 shows the results of such a gasoline tanker-train accident. Seven fatalities resulted from this collision, and 19 motor vehicles were destroyed by the resulting fire. In addition, if a hazardous materials truck is stopped at a crossing and a motor vehicle-train collision occurs, the possibility of a secondary collision with the hazardous materials truck presents a serious safety problem. Thus, as the number of hazardous materials trucks using a crossing increases, this safety issue becomes more severe.

School Buses or Public Transportation Buses Crossings with a large number of school buses or public transportation buses pose certain safety problems (see Figure 8). Although it is very unlikely that a school or transit bus driver would ever drive around a gate arm and place school children or adult passengers in a serious safety situation, nevertheless a secondary collision from a hazardous materials truck collision with a train can cause serious safety problems. As the number of bus crossings increases, the magnitude of this safety issue increases.

FIGURE 7 Results of collision of hazardous materials truck and train.

FIGURE 8 School bus and transit bus using crossing.

High-Speed Passenger Trains Crossings with high-speed passenger trains pose certain safety problems due to the possibility of a train derailment as well as the speed of impact of the train with a motor vehicle. Obviously the derailment of a passenger train has the potential for creating a large number of personal injuries and fatalities. Preventing a motor vehicle from moving onto the tracks in front of a high-speed passenger train is highly desirable. In situations where the crossing characteristics result in a desire to drive around a gate arm, four-quadrant gates with skirts will be very effective.

Continuing Accident Occurrences

Continuing accident occurrences at crossings with two-quadrant gates tend to indicate that the standard gate system is not performing as intended. This can be due to a number of reasons, some of which are not necessarily due to motorists who drive around the gate arm. However, when accidents continually occur, using four-quadrant gates with skirts to improve the safety of the crossing if a grade separation is not economically feasible should be considered. The target value of a four-quadrant gate system with skirts is substantially increased over that of a two-quadrant gate system.

Crossings with Consistent Gate Arm Violations

Crossings with consistent gate arm violations, which do not meet one of the preceding situations, also pose a continuing hazardous situation for the traveling public (see Figure 9). There seem to be some crossings that have an abnormally high number of drivers going around gate arms. In these situations four-quadrant gates with skirts will simply eliminate the violations.

Hardware Considerations

With the exception of the gate arms and skirts, all of the hardware and equipment used in the four-quadrant gates with skirts are standard parts, commercially available from several suppliers. Furthermore, the hardware and equipment are the same as those used in standard two-quadrant gates; thus, field crews are familiar with their installation, operation, and maintenance.

FIGURE 9 Multiple large trucks driving around gate arms.

A delay relay should be installed in the gate control system in order to stagger the operation of the near- and far-side gate arms. Also, due to the added weight of the arm and skirt assembly, more counterweights will be required on the panarms. This added weight causes no problem in system operation.

To minimize unnecessary or lengthy gate activations, motion sensors or constant warning time train detectors should be installed at crossings where there are switching operations or large variations in train speed. These sensors and detectors will minimize the time during which the gates block the crossing.

The innovative gate arms with skirts, made from kiln-dried redwood, performed successfully and proved that the concept was not only technically feasible but practical and economically feasible.

One point to raise concerning the gate arms and skirts is whether the skirts are cost-effective. The field experience suggests that four-quadrant gates alone may greatly enhance driver performance and safety, and that the additional benefits of skirts may be minimal. The addition of skirts certainly complicates device construction, installation, and maintenance, and increases the cost of a four-quadrant gate installation; however, it enhances visibility considerably, especially at night. Where the geometrics of the approaches are complex and a larger target value is required at the crossing, skirts readily enhance the target value of the gate arms.

Installation Considerations

Four-quadrant gates with skirts can be installed by regular field personnel within the normal scope of their duties and union contracts. No additional personnel training is required, nor are any special equipment, vehicles, or tools needed beyond those required for the normal installation of a gate system.

The procedures to install four-quadrant gates with skirts are basically the same as those used for standard two-quadrant gates, except for the following special requirements and concerns:

- Due to the increased weight of the skirt and gate arm, additional counterweights may need to be added to the panarms compared with those required for a standard gate arm. This additional counterweight will not affect the operation of the mechanism.
- When the gate arm and skirt are lowered and stopped in the horizontal position, there is a tendency for the unit to bounce or rock up and down a few times. To prevent the bottom of the skirt from striking the pavement during this bouncing, there should be 3 to 4 in. of clearance between the bottom of the skirt and the roadway.

System Operation and Maintenance

It is important that the gate arms be of sufficient length to completely block the roadway. If an opening of just a few

feet is left between opposing gate arms, motorcyclists and bicyclists may try to cross in front of a train.

There should be a time delay between the operation of the near- and far-side gates. That is, the near-side gate should start down first, with the far-side gate descent delayed by 5 to 7 sec. The actual delay time is based on vehicle lengths, crossing width, and vehicle operating speeds. The delay is achieved by installing a delay relay in the controller and adjusting the circuit resistance as appropriate.

Three red lights should be used on each gate arm. Thus, a total of six gate lights across the roadway on each side of the crossing would be used. The two outside lights should be operated in the flashing mode, while the four interior lights should be steady-burn lights.

The type of maintenance for four-quadrant gates with skirts is essentially the same as for standard two-quadrant gates.

Power Requirements

The system contains two more gate mechanisms and six more gate lights; thus it uses approximately 50 percent more power. The additional weight of the gate arms and skirts does not increase energy consumption significantly because this weight is accommodated by adding counterweights to the panarms.

Environmental Considerations

The experimental gate arms with skirts were subjected to a variety of environmental conditions. They performed well in high winds and heavy rains, and under snow and ice conditions. They did not swing or sway excessively, nor did they bind up, freeze, or snag. Also, the gates and skirts were essentially self-cleaning from rain.

Emergency Vehicles

Emergency vehicles need to be considered in implementing four-quadrant gates with skirts, particularly at crossings near hospitals and fire stations, or on routes frequented by emergency vehicles. Some ideas and issues regarding emergency vehicle handling are presented below:

- All affected service agencies should be informed in advance of alternate routes and what to do if a malfunction does occur during an emergency run.
- Gate arms that could be raised or rotated out of the way by emergency personnel either manually or electronically could be installed at crossings frequented by emergency vehicles. Also, the far-side gates could be designed to raise automatically if down for more than a specified period of time.
- The four-quadrant gates with skirts could simply not be considered for use at crossings frequented by emergency vehicles and where a suitable alternate route is not available.

It should be remembered that four-quadrant gates would only be a problem for emergency vehicles if the equipment malfunctioned. Obviously, if the gate arms are down because of a train approaching or on the crossing, the vehicle should not proceed. Thus, if malfunctions occur infrequently, four-quadrant gates with skirts should not pose any problems. If a malfunction does occur and a train is not approaching the crossing, an emergency vehicle could simply break the gate arm if the situation warranted.

HIGHWAY TRAFFIC SIGNALS

Driver response to the enhanced highway traffic signals was excellent (*3,5*). The field installation is shown in Figure 10. These signals proved to be both feasible and effective and performed better than standard flashing light signals in reducing the number of motorists that crossed less than 10 and 20 sec in front of an approaching train when predictors were used on both systems. In addition, the violation rate was low. In fact, the highway traffic signals performed similar to standard short-arm gates in discouraging unacceptable track crossings. Compared with flashing light signals with predictors, the highway traffic signal reduced the number of crossings per signal activation from 3.35 to 0.73, and reduced the risky behavior per train arrival from 0.13 to 0.05. ("Risky behavior" refers to the number of vehicles crossing while the flashing light signals are activated and within 10 sec of the train.) Furthermore, the highway traffic signals proved to be less expensive than flashing light signals and much cheaper than short-arm gates. These results suggest that enhanced highway traffic signals do indeed have application to railroad-highway grade crossings. In fact, study results indicate that highway traffic signals would actually improve crossing safety over that afforded by standard flashing light signals and at a reduced overall cost.

Applications

Study results further indicate that, with appropriate revisions to the MUTCD, enhanced highway traffic signals could be used at any crossing where flashing light signals are warranted.

FIGURE 10 Highway traffic signal system installed at Cedar Drive crossing in Knoxville, Tennessee.

Highway traffic signals have a high level of driver credibility and respect because they have been used prudently and have been well-operated and maintained in the vast majority of cases. If highway traffic signals are to be successful at railroad-highway grade crossings, and thus not compromise driver credibility for highway traffic signals in general, then the same high standards of operation and maintenance must be obtained at crossings as at highway intersections. In particular, highway traffic signals should not be considered at crossings where false activations or malfunctions are common. They also should not be used at crossings where the train warning or occupancy times are consistently unreasonably long, i.e., more than 60 sec.

Some crossing situations where highway traffic signals would regularly afford advantages over conventional flashing light signals are identified below:

- Crossings in the vicinity of a signalized intersection or in the middle of a system of signalized intersections, and
- Crossings with complex highway geometrics where drivers are unable to make proper judgments on whether it is safe to proceed across the tracks and where gates would be impractical.

Crossings in Area of Signalized Intersections

Motorists using a crossing that is located in the area of a number of signalized highway intersections are responding with regularity to standard highway traffic signals. To change to a new type of activated traffic control device, generally found nonactivated, requires some adjustments for a motorist from a human factors point of view. Increased perception-reaction times can occur for motorists in these situations through receiving a different stimulus for processing. In providing a repetitive environment for a motorist, there is merit in continuing to provide a standard highway traffic signal system network across a fairly large area to reduce the number of new or different stimuli given to motorists. Figure 11 shows an application of this concept in Denver, Colorado, and Figure 12 shows an application in Knoxville, Tennessee.

Complex Geometrics at Crossings

Traffic encountering complex highway geometrics at crossings is difficult to control with standard railroad active traffic control devices such as flashing light signals or gates. Complex highway geometrics create complex driving maneuvers on the part of motorists. Channelization of motorists becomes critical to ensure appropriate movement of motor vehicles in these areas. In addition, perception-reaction times can be significantly increased for motorists when encountering confusing geometrics or a complexity of active traffic control devices. Complex geometric multileg crossings are difficult to actively control with flashing light signals or gates. However, highway traffic signals, through the use of protected turning movements as well as arrows for directional movement and guidance, can be effective active traffic control devices at these types of crossings. Figure 13 shows an application of this concept in Oklahoma City, Oklahoma, and Figure 14 shows an application in Knoxville, Tennessee. Other complex geometrics can result from limited sight distances, grades on the approaches, alignment, as well as other factors. Highway traffic signals have a unique ability to provide positive guidance to a driver in negotiating complex geometrics of the highway system and thus increase the level of safety.

FIGURE 11 Highway traffic signals used at a crossing in Denver, Colorado.

Hardware Considerations

Except for the Barlo strobe lights in the red signal lenses, all of the hardware used is standard, off-the-shelf highway traffic

FIGURE 12 Highway traffic signals used at a crossing in Knoxville, Tennessee.

FIGURE 13 Highway traffic signals at crossing with complex roadway geometrics in Oklahoma City, Oklahoma.

FIGURE 14 Highway traffic signals at crossing with complex roadway geometrics in Knoxville, Tennessee.

signal equipment available from numerous suppliers in all parts of the country. This includes the signal poles and foundations, mast arms, signal heads, mounting hardware, wiring, controller, and advance sign or flashing beacon units. The ready availability of this hardware and the competitive price market certainly are advantages.

The Barlo lights are currently available only from one source, and production levels are low. Should the enhanced highway traffic signals be adopted for use, it is expected that the current supplier could meet demands at prices comparable to existing active device prices. Other manufacturers would also be expected to enter the market depending on patent restrictions.

Any type of signal controller can be used as long as it is capable of providing a three-part (red, yellow, and green), variable length cycle, along with a flashing red mode. Also, it is desirable to fully unify the signal controller with the train detection controller, placing them in the same cabinet and providing a unified power system.

Installation Considerations

Railroads have the experienced labor needed to install highway traffic signals. The alternative of using highway traffic signal contractors would also be available and, if labor union problems could be resolved, the total cost of installation should be significantly less.

No additional right-of-way or space (above or below ground) is needed for a highway traffic signal compared to a flashing light signal. However, if advance flashing beacons are used, some additional space along the roadway right-of-way may be needed for these devices. The installation of the beacons will generally be handled by the highway agency which would require some additional coordination.

Power Considerations

The enhanced highway traffic signal is powered directly by 120-volt commercial power. This power permits the use of higher wattage lamps (compared to flashing light signals). The higher wattage lamps are bright over a wide angle; thus alignment is not critical as with flashing light signals.

For the field studies, a propane generator was used to provide backup power for the highway traffic signals in the event of a commercial power failure. (Backup power for the train detection system was provided by conventional 12-volt batteries.) The propane generator was capable of powering the traffic signal for 24 hr or more. The generator performed without incident during the months of testing.

Power backup may not be necessary for a highway traffic signal installation since, unlike flashing light signals and gates, a traffic signal has a built-in fail-safe mode. When power is lost, due to a commercial power failure or malfunction, the signal indications go blank. A blank signal, in turn, warns motorists that there is a problem and that conflicts with opposing traffic are likely. Experience with conventional highway traffic signals indicates that drivers will be extremely cautious under these circumstances. Backup generators are not known to be used in the illustrations shown above.

It may be appropriate to define a fail-safe mode as a flashing red for standard highway traffic signals used at a railroad-highway crossing. This mode would not be difficult to achieve with a standard battery system used with standard active control devices. The highway traffic signal should be operated regularly on 120-volt AC power supply. However, should there be a power failure, a simple relay could be used to switch from the 120-volt AC power supply to the battery source to operate only a flashing red light by DC current. Without increasing the existing capability in standard battery installations at crossings, a flashing red mode could be maintained for a sufficient time to cover all but the most extensive power outages caused by storms. The increased safety benefits from the use of highway traffic signals should far outweigh any safety problems caused by power failures from a major storm.

Warning Time and Train Detection

The enhanced highway traffic signals can be easily and economically installed at crossings equipped with flashing light signals. However, for such retrofit installations (and for all new installations), consideration must be given to providing reasonable, uniform train warning times. Warning times (the time that the signal is yellow and then red before the train arrives at the crossing) will depend on the variability in approach train speeds and the type of train detection equipment. Reasonable and uniform warning times are essential to the successful operation of the enhanced highway traffic signals.

Experience suggests that most motorists will stop and wait for a red traffic signal for up to 60 sec, even if there is no opposing traffic in sight. This is true at signalized highway intersections and was also observed at the crossing test site. If the wait time exceeds 60 sec (particularly if there is no opposing traffic), the highway traffic signal may lose credibility for the motorist and violations are likely to occur.

At crossings with variable train speeds, it is desirable to employ constant warning time train detectors to provide warning times in the range of 20 to 30 sec. Constant warning time detectors should not be needed at crossings with uniform train speeds, because the speeds should result in uniform warning

times. Highway traffic signals will normally outperform flashing light signals in terms of reducing the number of motor vehicles going over the crossing after the signals are activated, even when both systems have constant warning times.

Traffic Signal Operation and Timing

The highway traffic signals should rest in green until the approach of a train is recognized by the train detectors. When the train is approximately 20 sec from the crossing, the signal should turn yellow and then red. The signal should remain red, with the white bar strobes flashing, until the train is past the crossing.

The length of the yellow vehicle change interval should be 3–6 sec, depending on approach traffic speeds. Recommendations for setting yellow times for highway intersections are presented in the MUTCD and *Traffic Engineering Handbook*, and these guidelines are applicable to grade crossing highway traffic signal installations (*1*, *10*).

A minimum warning time of 20 sec is more than enough to provide adequate train-car separation. In fact, a lesser warning time might minimize motorist delay, uncertainty, and violations, while still providing adequate train-car clearances. This time may be increased where conditions of vehicle length, acceleration characteristics, grades, number of tracks, or other factors dictate.

It must be recognized that hardware malfunctions (namely, false signal activations) are unavoidable. Furthermore, it would severely damage the credibility of a highway traffic signal installation at a grade crossing if the signal remained red during a lengthy malfunction period. Thus, it is desirable to have the signal change indications in the event of a malfunction. With standard signal equipment and controllers, the most practical way to accommodate false activations is to have the signal change to a flashing red indication after a sufficiently long period (long enough to know that the activation is not due to a slow train). A time of 3 min may be acceptable for most installations. This time should be based on specific conditions at the crossing such as train speeds and train lengths.

The highway traffic signal system installed in the field (shown in Figure 10) did not have crossbuck signs, advance warning signs, or advance pavement markings as a part of the traffic controls. The system worked extremely well and, thus, motorists treated the crossing as they would a signalized intersection. The intent was to have a motorist respond to the traffic control device rather than to whether or not a train is presumed to be approaching a crossing. It is recommended that all railroad warning signs (including the crossbucks and advance warning signs) should be eliminated. In their place, intersection stop bars and signal ahead signs with flashing beacons should be installed on the crossing approaches. Stop bars are essential, since the normal intersection cues are not present at a railroad grade crossing. In fact, STOP HERE ON RED signs may be used to supplement the stop bars.

Maintenance Considerations

Highway traffic signal installations require similar maintenance as a standard flashing light signal system. However, flashing light signals, as opposed to highway traffic signals, do require sighting. Maintenance of highway traffic signals could be handled by railroad signal maintainers with little additional training. Typical maintenance needs include the following:

1. The signal lamps must be changed and the lenses cleaned periodically,
2. Routine service checks on wiring and the controller are recommended, and
3. Periodically pavement markings must be replaced and the signs should be cleaned.

SUMMARY

The implementation considerations presented in this paper have been developed through field experience gained from research, consultations with the traffic engineering community, as well as many years of crossing safety experience by project staff. As these systems are implemented and are placed under additional field conditions, it is recognized that modifications may be needed. However, these guidelines will promote successful installation and operation of the two systems.

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DISCUSSION

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In the section entitled "Four-Quadrant Gates with Skirts," the statement is made in the second paragraph, "The four-quadrant gate system also did not interfere in any way with

emergency vehicle operations at the test crossing during the field evaluation." This statement addresses the universal concern that four-quadrant gates will block the passage of emergency vehicles when falsely actuated—a potentially life-threatening situation. Some reference should be inserted at this point to the qualifying comments in the paper in the subsection entitled "Emergency Vehicles."

In the subsection "Applications," "Crossings with large variations in train speeds and without constant warning time" are listed as candidates for the installation of four-quadrant gates. In the stated situation, any problem would undoubtedly be due to the absence of constant warning time (CWT) track circuitry and the installation of this circuitry would be the primary solution. Installation of four-quadrant gates in this situation would aggravate the delay to motor vehicles and would increase the likelihood of gate violation. Gate installation should not be mandated before CWT track circuitry is installed and tested. These comments apply equally to the subsection entitled "Crossings with Large Variations in Train Speeds and Without Constant Warning Time" and the subsection entitled "Crossings with Consistent Gate Arm Violations."

In the introductory paragraph to the section entitled "Highway Traffic Signals," the first sentence reads, "Driver response to the enhanced highway traffic signals was excellent." The discussant contends that the observed motorist response is the result of the novelty of this installation at a railroad-highway grade crossing and the conditioned response of the motorist to the traffic signal at the intersection of highways and not to any inherent superiority of the traffic signal display over the standard railroad flashing signal in controlling vehicular traffic at railroad-highway grade crossings.

The results obtained in this research are analogous to the results of the early research conducted with yellow and red Stop signs. However, after the red Stop sign was standardized and had been in use for some years, further research revealed that the driver response to the red Stop sign was practically identical to his response to the yellow Stop sign in the "before" condition of the early research, an example of the favorable but temporary effect of novelty.

The highway traffic signal is a continuously active device cycling on the average of once every minute and alternately assigning the right-of-way to intersecting flows of motor vehicles. It has functioned in this way and for this purpose since its inception and the motorist is conditioned to its meaning and his response.

The railroad grade crossing signal is an intermittent device cycling on the average of a few times a day that reaffirms the assignment of the right-of-way to the railroad and warns of the approach of the train. It, too, has functioned in this way and for this purpose since its inception and the motorist is conditioned to its meaning and his response.

In the opinion of the discussant, the use of the highway traffic signal at railroad-highway grade crossings would require the motorist to ascribe different meanings to the same device. The process of determining the proper response to the traffic signal before him must increase his perception-reaction time and ultimately, will be detrimental to his safety.

The highway traffic signals shown at the railroad-highway grade crossings in Figures 12 and 14 and discussed in the text are the proper display at these locations. The railroad tracks cross through the middle of the intersecting highways that operate full time under traffic signal control. Upon its approach, the train preempts the traffic signal that remains all red during the passage of the train. The successful use of railroad preemption at a traffic signal controlled highway intersection does not imply that highway traffic signals are the preferred device for the control of railroad-highway grade crossings.

AUTHORS' CLOSURE

We would like to thank Mr. Williams for commenting on this paper and we will attempt to respond to the questions raised.

Mr. Williams's comments on improving the track circuitry to ensure constant warning time as opposed to installing four-quadrant gates has some merit. However, when the improvements to the track circuitry cannot be achieved, installing four-quadrant gates would be better than having a large number of gate violations. Mr. Williams is incorrect in saying that the "installation of a four-quadrant gate system under these circumstances would increase the likelihood of gate violation." With the four-quadrant gate system, there will be no gate violations.

Mr. Williams may be correct in his comment that the response to the highway traffic signal could be due to its novelty at a railroad-highway grade crossing. However, we do not believe that this is the case. There has not been enough research conducted to conclude that the response is due only to a novelty effect. We believe that the response is due to the fact that a motorist has to respond to highway traffic signals frequently and, therefore, is conditioned to do so regardless of the location of the highway traffic signal.

The highway traffic signal is not necessarily a continuously active device cycling on the average of once every minute. This occurs only for a fixed-time signal. At intersections where only the minor roadway is traffic actuated, the amount of green time can be extremely long on the major thruway. Thus, motorists do encounter all types of cycling of the highway traffic signal including that found at a railroad-highway grade crossing.

From our research as well as other research, it is questionable whether a motorist is conditioned to the meaning of a flashing-light signal at a railroad-highway grade crossing. From our more than 25 years working in the highway safety field, we believe that many motorists do not fully understand what is required of them at a flashing-light signal. In fact, a flashing red light generally means stop and proceed with caution. This is also true for a railroad-highway grade crossing even though that may not be the correct driver response for a given situation.

At the beginning of our research project, we tended to agree with Mr. Williams in opposing the use of highway traffic signals at railroad-highway grade crossings. But after seeing the data and completing the analyses, we believe that there is merit in applying highway traffic signals to railroad-highway grade crossings. In more than 25 years in highway safety research, we have become convinced that the objective should be to minimize the number of traffic signals and signs to the extent possible. As the number of stimuli that a driver must respond to increases, the probability of error on the part of the driver also increases.

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