Grade-Crossing Warning-System Technology

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This paper reviews the objectives, content, and results of a large number of research projects sponsored by the Federal Railroad Administration and related to possible improvement concepts associated with motorist-warning systems at railroad-highway grade crossings. The benefits sought included increased effectiveness, reduced cost, and elimination of institutional constraints. The subjects that were investigated include the application of modularization concepts and alternative components in warning-control logic systems, cost reduction in automatic gate equipment, flashing lights using xenon flashlamp technology, functional requirements and the relevant equipment for lightning protection and standby power, and studies of alternative or novel warning system concepts. The potential for meaningful advances is found to be limited and is severely constrained by the technically challenging nature of the functional and safety requirements.

During the past decade an average of nearly 1300 people/year have been killed in collisions between trains and motor vehicles at railroad-highway grade crossings. Although the trend has been steadily downward, the magnitude of this loss, in what would seem to be preventable accidents, has generated increasing concern. One form that this interest has taken is that of federally sponsored research directed toward the technology of automatic warning devices. Although the causes of grade-crossing accidents—estimated at 12 000/year—are basically due to unsafe driver behavior, there is evidence that the installation of modern train-activated motorist warnings can provide dramatic safety benefits. Flashing lights alone typically reduce accident occurrence by 60 to 70 percent, and automatic gates reduce casualties by at least 90 to 95 percent in most cases (1, 2). Yet, little more than one-quarter of the 220 000 public crossings in the United States are equipped with such devices, largely because of the relatively low hazard associated with many of these crossings and the substantial cost of warning equipment. Also, the many accidents at railroad-highway intersections equipped with flashing lights or other active devices show that their effectiveness, as well as their cost, should be improved. Thus, even for this fundamentally nontechnological problem, research relating to warning-system equipment may significantly improve safety, possibly through more credible or more conspicuous warnings. Reductions in system costs could have a similar impact by permitting wider installation of active warnings or by allowing the use of more elaborate or sophisticated systems within a fixed budget. Innovative technology could also offer a means to circumvent institutional constraints on the implementation of protection. Finally, simply delineating and characterizing the performance and attributes of the available hardware permit more effective selection among the alternatives available.

CONTEXT AND SCOPE OF RECENT RESEARCH

The concepts on which current grade-crossing warning systems are based are not new. The train is detected by a century-old principle, the track circuit that drives a gravity-relay logic system. The flashing lights, gate mechanisms, relays, and such that are currently being installed strongly resemble the devices that have been used for decades. This equipment is highly reliable and virtually fail-safe. Over the years it has been continually improved, and recently solid-state electronic circuits and new materials have been used more and more. Very high levels of performance and reliability are demanded by users, and the attainment of these characteristics in severe operating environments has resulted in technically impressive but relatively expensive equipment. The hardware alone commonly costs over $10 000 for a simple flashing-light installation, and the cost at a multiple-track installation with gates or cantilever mountings or both is several times that. (Installation labor is typically an equivalent expense.)

Research efforts by the industry have always been constrained by basic economic considerations. On the one hand, the resources are limited: Until quite recently, the total market for grade-crossing warning equipment was only about $10 million/year, divided among several suppliers. Further, the results of even very successful research may be slow to appear. The high standards of performance and the very long lifetime required of equipment have made railroads very cautious about accepting new devices, and this inclination is increasingly supported by considerations of legal liability. Thus, under the best of circumstances, several years of successful field testing, which must be preceded by the full development of a new device, are necessary before a substantial market can be hoped for. On the other hand, the technical challenge to improve performance or develop lower cost designs without compromising reliability, safety, maintenance requirements, or resistance to the environment makes efforts in this area very costly, and the field-testing phase, which generally requires substantial redesign and refinement, can more than double the original investment. The possibility of failure is always high, and research efforts going significantly beyond creative product engineering are rarely possible or occur very slowly. The technical advances of recent years—audio-frequency overlay equipment, motion-sensitive detection, improved lights, the application of solid-state technology, the use of alternative gate-arm materials, and such—have been carried out almost entirely within the framework of existing concepts and practices and have typically required lengthy periods for completion.

These constraints have permitted significant improvements in system performance, but may limit the application of advances in industrial and aerospace electronic technology to the improvement of grade-crossing warnings. Thus, the Transportation Systems Center, under the sponsorship and guidance of the Office of Research and Development of the Federal Railroad Administration, has recently assessed the potential technical practicality and the economic viability of a wide range of alternative component and system concepts. The dominant goal of these efforts is improved grade-crossing safety, but in some cases this has been sought through cost reduction that would permit more widespread installation of active warnings or through better understanding of the technical and economic characteristics of the various alternatives.

The discussion presented here is limited to that of completed research on crossing-located, train-activated motorist-warning systems. Within that framework several distinctions are made: Advances within a basically conventional, track-circuit context are treated separately from truly innovative system concepts. And, within the former category, there is a natural distinction among control systems, gate systems, lights, and peripheral hardware. [More extensive descriptions of specific studies can be found in a number of reports (3, 4, 5, 6, 7, 8, 9, 10, 11, 12).] This paper comprises only a general presentation of the nature and scope of this wide range of research projects.

CONVENTIONAL EQUIPMENT

Control Subsystems

The potential for significant cost reduction through technical innovation that is still within the basic framework of track-circuit train detection and conventional motorist warnings has been examined in considerable detail (3, 4). The existing equipment and the practices now prevalent, including a detailed analysis of the equipment and installation costs for several types of crossings, were reviewed in terms of the four subsystems that comprise a train-activated warning system: train detection, control, motorist warnings, and interconnections. Within this breakdown, labor and equipment costs were also separated. Labor costs usually represented approximately one-half of the total expense, with about one-quarter of that being shop (rather than field) labor. The individual cost elements showed little potential for cost reduction in areas other than the control subsystem, and even in that area, savings of only 10 to 20 percent appeared attainable, implying a maximum of only 3 to 7 percent impact on the total cost. (Gate arms and drive mechanisms were explicitly excluded from detailed study in this project.)

This project included a process of generating, characterizing, and evaluating concepts by which equipment suppliers might improve their products. Several possible approaches were identified, and their potential benefits were balanced against their greater cost and the uncertainty associated with their realization. The most straightforward path appeared to be that of designing, constructing, and testing systems based on modular components, with different combinations of a small number of basic modules sufficient for simple assembly of the logic and control portions of most installations. In the simplest form, the modules would be based on combinations of existing gravity relays. Other possibly advantageous concepts would extend the modular approach by using alternative, lower cost types of relays or solid-state circuitry in place of the traditional vital relays, which are reliable and fail-safe but costly and physically large. These efforts were conceptual and analytical in nature—no hardware was designed or tested—and firm conclusions are not possible. However, a tentative finding was that the use of the type of signal relay common in Europe, which is highly reliable but based on self-checking rather than on inherently fail-safe design, should seriously be investigated. Mercury-wetted reed relays, which have not previously been used in this type of application, may also merit more detailed examination. Redundancy techniques, which are common in some high-reliability applications, did not appear to be attractive here. For special cases, solid-state components appear to be useful, but constraints relating to market size, temperature extremes, and surge protection make such devices less competitive than might be anticipated; their customary advantages of high operating speed, small size, and sophisticated functional capabilities are not of great value at grade crossings, for which the system logic is relatively simple and time constants of seconds are fully satisfactory.

Automatic Gates

Train-activated automatic gates generally provide a safety effectiveness (accident reduction) of 90 to 95 percent or better. However, their substantial cost has limited their use; a complete crossing using gates (but not cantilever light mountings) typically costs $35 000 to $50 000, compared to $20 000 to $30 000 for flashing lights alone. Although this large differential is partially due to the fact that gates are usually used at more complex crossings such as multilane and multitrack ones, gate hardware itself is not inexpensive and may be 10 to 20 percent of the total cost of the installation. Maintenance costs are also substantial.

Gate breakage is a major problem. Either accidentally or deliberately, it is not uncommon for motor vehicles to drive through lowered gates, or to snag the tip in attempting to go around them. The result is a breakage rate that averages more than 1 gate arm/year for each gated crossing, and may be far greater for particular crossings or localities. This problem may arise from unnecessarily long activation times or from false alarms in which no train reaches the crossing at all, which result in driver annoyance or frustration and lead to the decision to go through the gate rather than wait for it. Or, if the crossing activates just after a large trailer truck has entered it, particularly one that has just made a mandatory stop, the descending gate arm can catch on the vehicle and be damaged. Other sources of damage are vandalism and strong gusty winds. Some of these problems can be alleviated through direct means such as the use of constant-warning-time train detection, but the basic problem remains. Since arms cost $200 to $300 and require substantial installation labor (often at overtime rates), the economic burden on the railroads can be quite significant.

There has been continuing research in this area. The traditional double wooden arm has been challenged by fiberglass and aluminum alternatives, and recently a manufacturer not previously involved in this market has developed a polycarbonate (Lexan) arm. Gate mountings that shear, permitting the arm to drop free rather than break, have come into widespread use. Nonetheless, further improvements through application of recent advances in materials and structures are possible.

A clear distinction between required and desired arm characteristics is difficult to make: A number of features must be balanced within certain constraints. Some railroad personnel find gate-arm breakage useful in the event of an accident, as this provides evidence, which can be brought into court, that the gate was lowered at the time of an accident. Too rigid an arm could cause a derailment if it were to be knocked onto the tracks. An electrically conductive (metal) arm might be a safety hazard if it came into contact with power lines when in a raised position. The costs of providing resistance to initial breakage must be balanced against those associated with ease of repair, unless both can be combined.

The present gate-drive mechanisms have an impressive record of performance and reliability. However, several factors, including limited research resources and the existing industry standards, have limited the range of alternative approaches and components used. The application of recently developed materials, new structural concepts, and improved components might provide significant economic benefits without compromising performance, safety, reliability, or service life.

Accordingly, this area was studied (5, 6) through a sequence of tasks that included a thorough review of existing practices, specifications, and regulations; recommendations concerning areas in which modifications of existing requirements might permit significant overall cost reductions without compromising safety or performance; and the generation of new concepts for gate systems. These concepts were then subjected to as thorough an engineering and economic analysis as possible, and recommendations concerning possible future research and development were made.

Three areas, the gate-drive mechanism, the arm support, and the gate arm, were identified as targets for possible advances. The suggested concept for a low-cost drive mechanism that could offer significant cost benefits if all of its components should prove practical is based on combinations of several commercially available elements:

1. A high-speed sealed motor integrated with a sealed high-ratio, high-output-torque gearbox and output shaft;
2. A sealed ball-bearing unit that uses a long-life lubricant for support of the output shaft;
3. Sealed switches and relays of high reliability; and
4. A compact, weatherproof, lightweight enclosure.

The use of a small motor with a high gear ratio would require special attention to achieve a fail-safe operation (the lowering of the gate in the event of a power outage); this area would require specific and substantial investigation if this concept were to be pursued further.

Another possible approach is the use of a pneumatic drive mechanism, which has a number of attractive features.

Another concept suggested is that of a swing-away gate-arm support that uses a semiflexible arm on a pivoting mechanism. This allows the arm to swing up out of the way when struck and afterward return by gravity to its original position. For the arm itself, the use of new fabrication materials in basically conventional arm structures could offer substantial potential benefits: The material recommended is a phenolic resin-impregnated honeycomb encased in a fiberglass-reinforced polyester tube. An arm of this material used with an effective swing-away resetting mounting would cost substantially less over its potential service life.

Flashing Lights

Conventional grade-crossing flashing-light systems generally reduce accidents by 60 to 75 percent; these devices are by far the most common train-activated motorist warnings now in use. Yet, over one-third of the present fatalities occur at the approximately 50 000 higher traffic-density crossings marked by active warnings. The primary causes of these collisions appear to be motorist inattention, carelessness, misjudgment, error, or inebriation. However, since active devices have a strong positive effect, even these factors could be overcome (7, 13).

There are two usual assumptions concerning the needs of a motorist approaching a grade crossing. The first is that he or she is less likely to be aware of the presence and hazard of the crossing than of that of a normal highway intersection; hence, a high degree of alerting effectiveness is necessary. The second is that, since the situation and the hazard at a crossing are significantly different from those at a crossroad, the warning should be immediately and unequivocally identifiable as being associated with a railroad crossing.

A possibly effective and practical innovation is the use of the high alerting effectiveness and power-conversion efficiency associated with the very short flash duration (less than a millisecond) of xenon (strobe) lamps. It is technically a relatively simple matter to mount conventional xenon lamps in standard grade-crossing flasher heads in place of the normal incandescent bulbs, and to add an appropriate power supply. In the quiescent state the crossing appears essentially the same as with conventional lamps, but, when activated, the red strobe lights supplement the existing incandescent units in a highly alerting fashion. Subjective judgments of the potential safety effectiveness of xenon lights have been highly favorable, and some of their greater power efficiency could be used to provide a wider beam width, which would make them less vulnerable to misalignment.

Peripheral Subsystems

Two peripheral areas, which do not have major direct impacts on system cost but which are serious constraints on system design and reliability, are those of the protection of the equipment from the effects of electrical surges (primarily those associated with lightning) and the provision for emergency or backup power supplies.

Lightning annually damages or destroys millions of dollars worth of railroad signaling equipment in the United States. This problem has existed since the inception of electrical signaling and communication systems on the railroads. Protective devices and techniques have been developed to control this effect, but they do not eliminate it. The situation has become even more serious in recent years due to the increasing costs of repairs (particularly labor) and the introduction of solid-state electronic components, either to replace older electromechanical relay systems or to increase functional capability. Although the solid-state components are often useful, or even necessary for some devices, they are inherently more vulnerable to damage from lightning and other electrical surges than are traditional electromechanical devices. Although there are now available a wide range of surge-protection devices, as well as analytical techniques for better understanding of particular applications, these advances appear to have been used to a lesser extent in railroad signaling than in other areas. Standardized specifications for surge testing, surge resistance, and surge protective devices would also be desirable, and there would be a marked improvement after greater involvement of trained surge-protection specialists in the problems of railroad signal equipment.

A survey (12) of the requirements and technology relating to the provision of standby power to operate crossings in the event of failure of the commercial or other 110-V line power found that the railroads voluntarily assume far more rigorous standards in this matter than are imposed by public bodies, often requiring sufficient battery capacity to last between scheduled maintenance visits (1 to 2 weeks). Batteries with regulated charging units appear to be the preferred approach although there are a number of alternatives that may have advantages in certain situations. Solar power, for example, is beginning to find a small but significant role in powering railroad signal systems.

INNOVATIVE SYSTEM CONCEPTS

The relatively high interest in recent years in grade-crossing safety has generated many suggestions concerning possible improvements. Often, these ideas reflect a misunderstanding of the technology involved, the functional requirements of the system, acceptable economics, or accident-causal factors, but other ideas justify more thorough consideration. A study of the technical feasibility and potential benefits of truly innovative system concepts for train-actuated motorist-warning systems (14) is discussed below.

Communication Link

The track-circuit systems used almost universally in the United States detect train occupancy at any point in the signal block. A possible alternative is the detection of trains only at entrance and exit points, with that information then communicated to a central storage and processing point. This is a common practice in Europe. Two communication-link methods are possible: microwave telemetry, for which good power efficiency can be obtained by the use of tightly focused beams (8), and very-high-frequency radio transmission, which is not limited to line-of-sight operation (8,9). It may be that each method has a role to play, depending on particular circumstances; in any event, this affects only a small part of the system design and performance.

The principal technical difficulty with this overall concept is the selection of a train-detection device that meets all of the requirements of reliability, fail-safe operation, low power consumption, long lifetime, invulnerability to extreme environments, and low cost. At least one existing sensor appears to be adequate but costs over $1000 (several would be required) and must be attached to the tracks. A variety of physical principles that might lead to a lower cost device have been identified, but any serious development effort would inevitably be lengthy, expensive, and of uncertain outcome, since this element is at the heart of safe system operation and must meet very rigorous performance and reliability standards.

However, the potential cost reduction of the communication-link approach appears to be limited, and there is a definite possibility that its price would ultimately exceed that of conventional systems. Its functional advantages are also uncertain: The use of speed-sensitive train-detection devices might facilitate constant-warning-time operation, but there is considerable system complication when one attempts to equal the performance of conventional motion-sensing equipment. The major advantage of this concept is the possibility of realizing a system that could be operated by a public authority, such as a highway department (15). The use of track circuits now involves the railroads so intimately that this is virtually impossible. However, the full benefits of this course of action would require retrofitting many of the more than 50 000 crossings that now have conventional train-activated warnings.

Radar Train Detection

The use of crossing-located radar has been a popular idea for several years, partially stimulated by the availability of simple solid-state radar modules and apparently analogous uses in motor-vehicle speed monitoring, small-boat safety, and military-perimeter surveillance. However, as a train-detection method, this concept has numerous weaknesses, particularly in line-of-sight restrictions, the absence of fail-safe operation, and inadequate performance at multiple-track crossings or those near parallel highways. In addition, even the partial satisfaction of the necessary rigorous specifications escalates costs to an unacceptable level. While such an approach might someday be practical as a parallel subsystem for providing constant-warning time, it is unlikely to be viable as a primary means of train detection.

Track Radar

One new form of track circuit that appeared promising is significantly different from present track circuits in that it does not rely exclusively on circuit characteristics, but on the return reflection of audio-frequency electrical signals transmitted down the track from the crossing. Through the use of correlation circuits the elapsed time from the origination of the signal to the receipt of its reflection can be measured to give a precise indication of the location of the reflecting element—typically a train, short-circuiting the rails. The velocity and direction of the movement of the train can in principle be determined by following its location as a function of time, so that the constant-warning time can theoretically be obtained. This system should permit automatic compensation for changes in the electrical properties of the track and ballast. However, the basic principle of operation has not been demonstrated in practice, or even analyzed in depth, and the electrical variability of typical track structures will undoubtedly pose difficulties. The sophisticated equipment required might make the method too expensive to achieve.

Locomotive-Mounted Transmitters

Another frequently suggested concept involves devising a means by which a locomotive can signal the crossing of its impending arrival. A number of variations are possible and lead to systems that differ widely in cost and probable performance. The simplest variation might be a continuously operating locomotive transmitter that activates warnings at all crossings within range. The next level of complexity would provide for transmission only when the train is approaching or occupying a crossing, with activation of the transmitter occurring through manual means or some wayside device in advance of the crossing. Far more elaborate concepts could also be generated; for example, a locomotive might have an odometer to monitor its exact location continuously, with the transmissions coded for particular crossings and activated from a route specification stored in a microprocessor memory, which could also accommodate the train speed.

There are weaknesses inherent in all of these concepts. In general, they require the sacrifice of the fail-safe principle that has guided railroad signal practices for many decades. In them, the normal condition at the crossing—no signal received—is no different for the case of the approach of an unequipped or malfunctioning locomotive than it is for no train approaching. Although this difficulty could be circumvented by operating rules and engineer intervention, it is still a non-safe-failure mode. In addition, there is the serious limitation that all locomotives and other power units would have to be appropriately equipped for the system to be totally effective and safe at even a single crossing. Thus, widespread application at crossings would be required to justify the modification of the locomotive fleet.

A simple device that activates crossing signals indiscriminately might generate so many unnecessary or excessively lengthy advance warnings as to lose all credibility with motorists, and even this type of system could be relatively costly when fabricated to high standards of equipment reliability. On the other hand, dependence on the train crew to deal with all cases, or merely the exceptions, imposes an additional burden on them and introduces a major potential point of controversy in the event of an accident.

One can envision a system in which a locomotive arriving at a crossing interrogates a passive wayside device, receives a coding for that crossing, and transmits the appropriate signal to activate that crossing only. This system could also incorporate on-board speed sensing and alter the warning as required. A specific sensor would be needed at the crossing to deactivate the warning after the entire train had passed. It would also be possible to require that a crossing-located transponder answer the locomotive when the signals were activated; the failure to respond in a brief interval would alert the engineer to the possibility that the crossing warnings had not been activated. However, these more elaborate concepts will be expensive, which will limit their attractiveness as compared to conventional warning systems. On the other hand, the simpler, lower cost systems will not be as effective in warning the motorist at the crossing. The most reasonable concept is probably an essentially manual approach in which the engineer activates the transmitter when necessary and attempts to stop if no confirmation is received, and this is combined with a very simple, low-cost warning such as a single strobe light at the crossing. It would be important that motorists be able to distinguish between this possibly unreliable indication and the standard fail-safe signals, to avoid any diminution of the effectiveness of the latter. An approach of this type might be only slightly inferior in safety effectiveness to conventional equipment, but at a far lower cost. The major use of such a warning system would be for crossings with lower traffic volumes that do not justify the expense of current systems. However, it is not clear that this type of compromise is attainable and cost-effective, nor that it would be generally acceptable to safety authorities or the public.

Train Indicator

Under various specialized circumstances, both in Europe and in the United States, train indicators, wayside signals to the locomotive engineer that forbid entry into a crossing until the motorist-warning system has been activated, have been used. This broad concept can be implemented in many ways, but often involves a fail-safe arrangement in which the wayside signal (train indicator) is normally red and changes to green only when the crossing signal is on. The typical use is on heavily traveled roads that are crossed by infrequent, short, low-speed trains that can easily stop if necessary; in some cases the normal procedure is for the train to stop so that the train crew can manually activate the warnings. However, this concept could be used in a way that might permit significant reductions in the cost of warning equipment. At sufficiently low speeds, even a moderately large freight train can stop within the normal grade-crossing-approach circuit distance if the crossing warning does not activate. Even for a relatively long, heavy train, this condition would be satisfied at train speeds of up to approximately 32 km/h (20 mph). For shorter trains, or a longer than normal prearrival warning time at the crossing, the situation is still less restrictive. Thus, this approach could be used for crossings for which factors such as track conditions limit speeds sufficiently. This is not to imply that trains should be stopped at crossings or that speed limits should be reduced. In addition to the havoc this could play with schedules and operating costs (there is approximately 0.6 public crossing/railroad route-kilometer in the United States, with 1 in 5 marked by train-warnings), such an approach would lead to trains moving over crossings slowly or from a dead stop, which would generally increase exposure time (and thus hazard) and highway congestion. However, by the use of such systems, the very high equipment-reliability standards now imposed might be relaxed. Since the last increment of reliability is typically very expensive to achieve, this might be a way to reduce cost with no appreciable loss of safety and a very low probability that a train would, in fact, have to stop.

This concept is highly speculative. Its viability depends on the number of crossings to which it might apply and their accident potential. It further makes the unproven assumption that major cost reductions could be achieved with no more than a very small diminution of system reliability and no increase in maintenance requirements. Nonetheless, it could be of interest for the large number of crossings that are not hazardous enough to justify the expense of conventional warning systems but are the locations of a significant number of accidents.

CONCLUSIONS

The goal of achieving significant cost reductions and increased safety effectiveness at railroad-highway grade crossings purely through technical innovation appears to be attainable only to a limited degree and is technically very challenging. No concepts that offer dramatic improvement in system economics have been generated, although a number of avenues that might lead to significant, if modest, cost savings have been identified. These are primarily improvements in gate arms and drive mechanisms and in control-system modularization, possibly using logic elements other than gravity relays.

A promising potential advance in safety effectiveness is in the use of xenon flashlamps (strobe lights) at grade crossings, where the conspicuity and alerting impact of the short-duration flashes would be a significant improvement. This would also generate economic benefits through the elimination of the requirement for extremely stable (and expensive) cantilever mounting structures that are more costly than gates.

A high degree of consistency in the advance warning time of crossing signals enhances their credibility with motorists and therefore improves safety. However, none of the suggested alternative methods clearly represents an improvement over current techniques, and this area is sufficiently important to justify further investigation.

The existing technical barriers to the transfer of the operational responsibility for crossing warnings could be overcome with a sufficiently strong motivation. However, the required development effort would be substantial, and the equipment cost is unlikely to be lower. Thus, the ultimate attractiveness of this course depends on factors and judgments that are not appropriate to this discussion.

The available array of warning systems lacks equipment that is sufficiently low in cost for truly widespread installation, even at crossings of quite low hazard, but the development of this equipment is unlikely to be achieved without some diminution of safety effectiveness, a consequence that has generally not been considered acceptable. Concepts such as those of a simple locomotive-mounted system or a train indicator could offer substantial overall safety benefits, but raise serious questions of policy in public-safety matters.

These conclusions are only tentative, partially subjective, and based on the present understanding of the causes of the problem and of relevant technologies. Should the potential advantages be sufficiently attractive, further research would be necessary to confirm and define more precisely the magnitudes and values of possible improvements. Such decisions must be made within the context of the practicality and acceptability of new approaches to a system that is now structured around particular safety requirements, technology, skills, inventory, and maintenance standards. The development of the actual equipment would be a lengthy, expensive, and inevitably somewhat speculative endeavor. On the other hand, the range of possibilities and concepts that has been identified by the research described here suggests opportunities and may stimulate significant advances in this long-standing problem of public safety.

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No claim of originality is made for many of the concepts here identified, and some may even be protected by existing corporate patents. The judgments expressed here represent in part the personal opinions of the author, deriving from experience and professional judgment, but nevertheless are not to be taken as final or absolute. In particular, these comments do not necessarily represent the views or policies of the U.S. Department of Transportation, the Federal Railroad Administration, or the Transportation Systems Center.

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Traffic-Control Measures at Highway-Railway Grade Crossings With Provisions for Light Rail Transit

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Railway rights-of-way in cities are attractive alternatives for transit corridors, but, for modes that are not fully grade-separated, such as light rail transit systems, there may be problems with combined railway and transit crossings of arterial streets. This situation has been studied in Edmonton, Alberta, where a light rail transit line is under construction. The surface portion of this line is along the railway right-of-way, and as a result, the operation of its eight grade crossings is regulated by railway authorities. The short headways of light rail transit could cause frequent disturbances to the road traffic that operates at saturation during peak hours. This paper illustrates the method used for the analysis of the problem and discusses the surveys conducted. The basic principles governing the solutions to the grade-crossing problem are (a) the coordination of adjacent signalized intersections in such a way that the impact of the crossing closure is minimized and the system recovers shortly after the closure, (b) the integration of light rail transit scheduling and control with traffic control, i.e., restricting the closures to the periods of minimum impact on road traffic, and (c) the use of special features to increase safety.

The northeast sector of Edmonton contains industrial and recreational complexes and has a residential population of approximately 100 000 persons, which is expected to increase to 150 000 persons by the year 1980. One-third of this growth is expected to occur in new outlying areas, and the balance will be in the presently developing areas and the older developed areas.