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Summary of Highway/Rail Intersection Research at the Texas A&M University ITS Research Center of Excellence

TTI/ITS RCE-99/02

Texas Transportation Institute • The Texas A&M University System • College Station, Texas

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16. Abstract

This report constitutes a compendium of the results of many years of research at the Texas Transportation Institute working to improve highway/rail intersection safety. Developments over the years of new technologies in sensing, communications, and information presentation offer the opportunity to further improve highway/rail intersection safety beyond current state-of-the-practice.

The advent of the Intelligent Transportation System (ITS), formerly referred to as the Intelligent Vehicle-Highway System (IVHS), adds an even broader dimension to transportation management research opportunities at highway/rail intersections. The addition of the highway/rail intersection into the architecture (User Service 30) has led to the preliminary investigation and evaluation of potential ITS applications for rail-related activities.

The rail integration activities conducted by the Research Center of Excellence thus far have been focused on providing the information needed to ensure that User Service 30 is an integral component of the National ITS Architecture. A summary of the current information exchange (first generation technology) between highway/rail intersections and traffic signal controllers has been compiled in an effort to provide the concepts associated with current practices. This report also summarizes the second and third generation information-sharing concepts that are currently under development to improve surface transportation management. With advancements in ITS technologies, it is possible to share more information between rail and highway operations to further improve safety and mobility.

A review and comparison of the current management concepts associated with intelligent train control and intelligent traffic control was conducted in an attempt to formulate a conceptual ITS structure designed to incorporate rail activities in the surface transportation management network. Further research associated with highway and railroad interaction has the potential to enhance both management activities as well as establish the basis for providing local and advanced traveler information exchange.

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Research Report 99/02
Research Project: Integrate Railroad Information into Advanced Traffic Management Systems

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TEXAS TRANSPORTATION INSTITUTE
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1. INTRODUCTION

The highway/rail intersection has been a research initiative under the transportation management focus area of the Texas A&M ITS Research Center of Excellence. This initiative was the result of many years of research at the Texas Transportation Institute working to improve highway/rail intersection safety. The availability of new technologies in sensing, communications, and information presentation offered the opportunity to improve highway/rail intersection safety.

Motor vehicle/train accidents and non-train motor vehicle accidents associated with highway/rail intersections continue to generate concern. Statistics suggest that approximately 60 percent of all highway/rail intersection accidents occur at locations equipped with train-activated warning devices. Although arguments presented to explain these statistics suggest the majority of highway/rail exposure is found at intersections having active devices, and that the problem is more related to driver behavior than the technology utilized for warning, there still appears to be an opportunity to potentially improve highway/rail intersection safety. For example, if the number of vehicles required to stop at a highway/rail intersection is reduced, then the exposure factor is reduced independent of driver behavior issues.

The purpose of this report is to summarize the activities undertaken by the Research Center of Excellence to integrate highway/railway intersections into an intelligent surface transportation system. Recent initiatives within the North American railroad industry to develop advanced train control systems (ATCS) and related technologies, such as positive train separation (PTS)/positive train control (PTC) have provided the opportunity to take a fresh approach for the detection of trains at highway/rail intersections (1). The advent of the Intelligent Transportation System (ITS), formerly referred to as the Intelligent Vehicle-Highway System, adds an even broader dimension to transportation management research opportunities at highway/rail intersections.

Historically, interconnection of control devices with railroad signal controllers, specifically standard highway traffic signals, have been restricted to those devices in close proximity to railroad right-of-ways. Significant advances in traffic control systems that manage complex networks of streets and highways could be further enhanced by the integration of rail information. Both the highway and railroad entities possess information that could help coordinate safer train movements through highway/rail intersections.

The common type of highway/rail integration utilized today is based on limited information exchanged between highway/rail intersection warning devices and traffic control signals. A continuous signal is generally transmitted from the highway/rail intersection signal to the traffic signal, verifying that a train is not approaching the highway/rail intersection. This type of circuit connection has been developed based on what is commonly referred to as the "fail-safe" design principle in the railroad industry. When a train or railroad track vehicle enters the track circuit system, the "fail-safe" interconnect circuit, connected to the adjacent traffic signal controller, is broken by opening a relay in the circuit. This open circuit notifies the traffic signal controller that there is activity on the tracks, and a track clearance and preemption sequence should be initiated. This activity is detected utilizing one of two information/data exchange concepts: simultaneous preemption or advanced preemption.

The simultaneous preemption concept (commonly referred to as interconnection) involves simultaneous activities of both the highway/rail intersection and traffic signal controller. This concept is relatively simple and reliable, providing the same amount of advanced warning to the traffic signal controller as the highway/rail intersection signal provides to the motorist (normally in the 20 to 30 second range). This is a recommended practice (and also the most predominant form of preemption) in situations where traffic queues of significant length are not common at the highway/rail intersection. A more sophisticated information exchange concept involves an advanced preemptive signal from the highway/rail intersection signal controller to the traffic signal controller. The additional amount of time needed to facilitate the proper operation of the traffic signal is normally based on queuing problems or other types of traffic operational problems. Because trains cannot be stopped quickly, none of the traffic operational activities associated with the traffic signal systems can take priority or have preference to train movements. These activities include pedestrian signal phasing, emergency vehicle actuation devices, and any other sensitive traffic operation functions.

2. RAIL INTEGRATION

The original 29 User Services established for the National ITS Architecture failed to properly address the highway/rail intersection as a special case of a traffic signal. Mr. Hoy Richards of the Texas Transportation Institute responded to the original Federal Highway Administration's Intelligent Vehicle-Highway System Docket requesting the inclusion of the highway/rail intersection into the Intelligent Vehicle-Highway System (now ITS). He went on to prepare a document through the Research Center of Excellence which became the basis for the inclusion of User Service 30 into the National ITS Architecture (2).

2.1 USER SERVICE 30

The addition of the highway/rail intersection into the architecture has lead to the preliminary investigation and evaluation of potential ITS applications for rail-related activities. The rail integration activities conducted by the Research Center of Excellence thus far have been focused on providing the information needed to ensure that User Service 30 is an integral component of the National ITS Architecture. The dynamic nature of the entire integration concept creates an environment where excellent ideas or concepts are short lived and have a significant need for continuous revision or reevaluation. The complexity and rate of change of the hardware, software, and communication infrastructure associated with ITS activities, commands a level of attention to detail that has not historically been prevalent in many transportation engineering related activities.

The concept of exchanging or sharing traffic-related information between highway entities and railroad companies, commonly referred to as highway/rail system integration, covers a fairly broad range of activities including the current state-of-the-practice, enhanced methods utilizing existing technologies, and technologies that are currently under development. For clarification purposes, the rail integration concepts currently under evaluation at the Texas Transportation Institute have been categorized into three separate areas. These categories have been identified as first, second, and third generation technologies.

2.1.1 First Generation Technology

The expanded utilization of this type of detection technology is being investigated through the efforts of the Research Center of Excellence at the Texas Transportation Institute and has been defined as the common type of highway/rail integration utilized today. This concept is based on the current level of information exchanged between highway/rail intersection warning devices and traffic control signals. A continuous signal is generally transmitted from the highway/rail intersection signal to the traffic signal, verifying that a train is not coming. This type of circuit connection is commonly referred as the "fail-safe" design principle in the railroad industry, indicating that the signal will be activated continuously during a circuit failure. This activation occurs when the continuous signal transmitted to the traffic signal is "shunted" or ceases to exist. The events are detected utilizing one of the two information/data exchange concepts mentioned earlier: simultaneous or advanced preemption.

The two categories of preemption are based on the amount of time actually provided prior to the arrival of a train at the highway/rail intersection. The simultaneous preemption concept (commonly confused with the physical connection or interconnection between the two signal controllers) involves simultaneous activities of both the highway/rail intersection signal and traffic signal. The advanced preemption concept involves the activation of the traffic signal prior to the activation of the highway/rail intersection signal system. Advanced preemption was developed to initiate traffic signal activities prior to the activation of the highway/rail intersection signal at a specified time frame requested by the entity having jurisdictional authority for the roadway. The additional amount of time needed to facilitate the proper operation of the traffic signal is normally based on queuing problems or other types of traffic operational problems.

Because trains cannot be stopped quickly, none of the traffic operational activities associated with the traffic signal controller can take priority or have preference to train activities. These activities include pedestrian signal phasing, emergency vehicle actuation devices, and any other sensitive traffic operation functions. The primary objective of the current Research Center of Excellence efforts are focused on better utilization of the information currently provided, increased awareness of the issues, and further enhanced safety and operational aspects associated with highway and rail interaction at highway/rail intersections. The limited amount of advanced knowledge available from current preemption strategies or first generation practices generated from upstream interconnected highway/rail signals and traffic signals could allow for the omission or alteration of current traffic signal phasing patterns, including pedestrian phases at downstream interconnected highway/rail and roadway intersections. Some conceptual ideas that are relevant to these activities include the development of better traffic signal transition sequencing when a preemption call is received, and better transportation management strategies when returning from preemption. The Research Center of Excellence has been involved in the preliminary development of both strategies which are designed to enhance traffic operations before and after railroad preemption occurs. Both concepts are focused on managing the highway/roadway traffic around train movements because of the limited amount of authority highway/roadway entities have with regard to train movements.

The conceptual forms of these strategies are currently under development. They feature logic that only allows vehicular and pedestrian phases that conflict with the track clearance phase to be displayed if there is adequate time to safely service those phases before it is necessary to advance to the track clearance phase. Ultimately, these strategies have the potential to yield more efficient operation of the traffic signal as it relates to motor vehicle movements and safer scenarios for pedestrian movements. Such strategies would be applicable at locations where either advanced or simultaneous preemption is currently provided.

The Research Center of Excellence is also currently in the process of developing similar simulation data and controller software for operating a traffic signal in conjunction with other traffic signals. Once the preemption event ends in a controller that is part of a coordinated system, the controller must return to coordinated operation. This almost always means that the controller must use a transition algorithm to adjust the offset of the phase sequence. There are two basic approaches (and many more variants) that are typically used: 1) lengthen one or more phases until the offset of the signal is in step with the coordinated system or 2) shorten one or more phases until the offset of the signal is in step with the coordinated system. Generally, a hybrid of the above approach is used, called "short way," where the worst case resynchronization time is calculated for 1) shortening all phases proportionally—nominally 17 percent and 2) lengthening all phases proportionally—

nominally 17 percent. Which ever approach is quicker determines if the phases are shortened or lengthened. Worst case resynchronization time is nominally three cycles (50 percent/17 percent).

Recent research by the Texas A&M Research Center of Excellence has evaluated the operational impact of alternative resynchronization algorithms on the Wellborn Corridor in College Station. In that research, a series of experiments were developed using the three National Electrical Manufacturers Association (NEMA) controllers. A FHWA corridor-microscopic simulation model (CORSIM) was utilized to simulate traffic demand and calculate measures of effectiveness (MOEs). A series of preemption events were introduced at various points in the coordinated cycle, and the performance of alternative cycle transition algorithms were evaluated.

Although not exhaustively demonstrated, the basic outcome of that research suggested that utilizing simple short-way algorithms is **not** the most efficient approach. The reason is that 50 percent of the time phases are shortened. When phases are shortened, problems on phases that were not serviced during the preemption event are further exasperated. Furthermore, methods designed to only lengthen phases were not always effective because in the extreme case, an offset might be off by only one second but have to go "all the way around" to get back in step.

These preliminary research findings indicate that a modified short-way transition algorithm could shorten, say, 5 percent, but lengthen 17 percent. However, the reader is cautioned that the above percentages are only approximate, and further study is warranted.

2.1.2 Second Generation Technology

Second Generation detection technology is being investigated through the efforts of the TransLink® Research Center at the Texas Transportation Institute and has been defined as the next step in the modification of rail integration activities. The TransLink® Research Center was developed as a supplemental program to the Research Center of Excellence through a public/private partnership with a primary focus on the development of the exchange of information between the various modes of the surface transportation system. Several approaches may be feasible for this type of information exchange, including traditional and non-traditional types of detection of train activities associated with highway/rail intersections.

While many of the existing traffic detection technologies traditionally utilized for roadway applications have been successfully developed for vehicle detection, they are considered non-traditional methods for railroad detection. The types of vehicle detection utilized for many other modes are considered non-intrusive detection methods when applied to train detection because they do not require direct input from the railroad companies for railroad-related detection activities. These types of detection devices will allow the development and deployment of highway/rail intersection data links to a transportation management center without the direct input of the railroad companies. They are currently under development in the TransLink® Roadside Equipment Laboratory and elsewhere, including the San Antonio model deployment initiative. Deployments of this nature will facilitate transportation management by the roadway entities and could provide a method by which highway/rail transportation management concepts could be evaluated for benefit to the railroad or the road authority. Demonstration of the feasibility of these types of information-sharing activities are currently being conducted by the TransLink® Research Center and are expected to be an integral component in the development of highway/rail intersection and traffic signal integration.

Another method of providing train-related information to a transportation management center involving traditional train detection technology is currently in the planning stages at the TransLink® Research Center. This effort would focus on the utilization of advanced features of standard railroad technology to establish estimated arrival times for trains at specified highway/rail intersections within a corridor. Recent developments by the leading manufacturers of highway/rail intersection warning devices allude to the fact that train arrival and departure times, and track location information can be established from traditional highway/rail intersection control devices. Institutional issues lessen the likelihood that this type of information sharing will be utilized prior to the development of the non-intrusive concepts.

2.1.3 Third Generation Technologies

Positive train separation (PTS) is an electronic train monitoring and control system designed to utilize global positioning satellite (GPS) data to verify the location of a train. PTS is often used interchangeably with PTC, though they refer to two distinct concepts. PTC, as defined by the FRA in reference to next generation train control, is "the application of technology in various subsystems that intervene to prevent trains from operating at a speed in excess of the maximum allowed, movement past any point of known obstruction or hazard, and movement beyond the limits authorized." The FRA defines PTS as the next generation of train control systems dedicated to the "application of technology to control the movement of trains in a manner that precludes the occurrence of collisions" (1).

The Association of American Railroads (AAR) recently voted to invest $20 million, to be paid in annual $5 million installments over four years, towards the revitalization of a PTC project being conducted by the Illinois Department of Transportation (3). The project has been rescheduled for a segment between Chicago and Springfield, Illinois, and illustrates a substantial commitment on behalf of the railroads toward this type of system because of the amount of funding being provided by a railroad organization.

A demonstration project utilizing PTS is in progress with an agreement between the Burlington Northern Railroad, Union Pacific Railroad, and GE Harris to deploy PTS on shared trackage in the Pacific Northwest region of the United States. This pilot program will address the three primary safety objectives associated with PTS, namely prevention of collisions between trains, prevention of collisions involving trains and track maintenance personnel, and prevention of over-speed train operation. The Texas Transportation Institute, in cooperation with the Washington State Department of Transportation and both freight railroads, has initiated the development and evaluation of highway/rail intersection innovations in conjunction with this PTS test bed, including the development of a wayside highway/rail intersection controller that interacts directly with the PTS system.

3. REVIEW OF HIGHWAY/RAIL INTERSECTION INTEGRATION TECHNOLOGIES AND CONCEPTS

Historically, rail and highway intelligent transportation concepts have been developed in separate arenas. The advancement of more intelligent operations have been directed more toward individual efforts that tend to lack the infrastructure needed to exchange information between the distinct modes. This section will focus on developments in the rail and highway arenas and explore the potential that exists for better information sharing to create a platform for the better overall management of these distinct surface transportation modes.

3.1 INTELLIGENT TRAIN CONTROL MANAGEMENT CONCEPTS

A review of current practices and emerging concepts related to rail integration has been an ongoing process during the Research Center of Excellence efforts focused on the integration of rail information into a transportation management center. For years, railroad companies in North America have been involved in the development of an elaborate train control system that covers a large percentage of the railroad network. This type of system is often referred to as a centralized train control system and is based on the concept of separating the rail lines into specific segments, or "blocks," that are defined by "control points" (4). The blocks are defined by various components of the rail system and are designed to provide train occupancy information to the central control center of the railroad. This system also provides the central control center personnel or dispatchers the ability to operate switches, wayside train control signals, and certain defect detectors from the central control center. The blocks may be associated with siding tracks, passing tracks, or switching turnouts that define locations along the tracks where there is potential for conflicting train movements.

From an intelligent transportation system standpoint, this type of system is probably the most elaborate system currently deployed in North America today. The shortcomings of this type of system, however, are related to the fact that the railroad companies can only approximate the location of a train within one to three miles of the actual location. The information provided by the system simply tells the railroad dispatchers in the central control center whether or not a block is occupied by a train. The block segments vary in length, with standard lengths of block in the one to three mile range. The primary function of the block system is to allow the dispatcher to maintain authority over train movements, substantially enhancing the safety of train operations. Consequently, while the railroads have one of the most, if not the most, comprehensive control systems deployed in North America, the information provided is not accurate enough to provide extremely valuable information to a transportation management center for ITS purposes.

3.1.1 Advanced Train Control System

An advanced train control system (ATCS) involves the application of computers, digital data communications, and other advanced technologies transmitting information to the control center of the railroad, locomotives, maintenance-of-way and inspection forces, and other elements of the railroad infrastructure (5). The ATCS concept took form during the mid-1980s, led by the communications and signal departments if several major railroads. Today, under the leadership of AAR, the railroad industry has determined the requirement, system architecture, and specifications for an ATCS. The technological improvements that will be made with an ATCS promise broad benefits for operational efficiency, employee and public safety, and customer service.

Several major North American railroads are in the process of implementing these initial projects, with the goal of eventually integrating an ATCS into their operation systemwide. Implementation an ATCS will require equipping locomotives with a train location system, onboard computers, and a data radio. The global positioning satellite system has been proposed for satellite reporting of train location. Transponders located at wayside or embedded in the railroad track are proposed to identify and monitor train operations at critical control points, replacing the functions provided by today's electrical track circuits. The on-board computer and data radio facilitate wayside-to-cab transmission for communicating speed and track occupancy to authorities, and cab-to-wayside communications for control of track switches. Many of these technologies are already seeing limited use in North America in ATCS demonstration projects and field tests (4). The actual full scale deployment of these type of systems will more than likely take several years.

3.1.2 Positive Train Separation

The PTS system "electronically displays operating instruction governing safe train movement from train dispatchers to train crews in locomotives" and "automatically alerts a train crew if there is, or will be, a violation of instructions and, if necessary, bring the train to a safe stop" (6). In many respects, PTS is a scaled-down version of an ATCS. PTS would include the type of safety system present in an ATCS but without many of the more complex and costly applications that have been described. PTS was publicized in 1993 and 1994 following a series of fatal rail mishaps, which proponents of PTS argued could have been avoided had PTS been enforced. One proposed system of PTS would require a block signal system on any trackage with train speeds in excess of 40 mph, and cab signals would be required on all routes with speeds of 60 mph or greater. A Congressional mandate required the Federal Railroad Administration (FRA) to report on PTS by July 1994 (7). The Burlington Northern and Union Pacific railroads have conducted preliminary testing of PTS on a segment of shared trackage in the Pacific Northwest and are currently in the process of Phase II of the development of PTS which will implement the PTS system in the Northwest Corridor.

3.1.3 Automatic Equipment Identification

The U.S. railroad industry recently implemented an Automatic Equipment Identification (AEI) system (8). A radio frequency (RF) based technology developed by Amtech Corporation was originally endorsed by AAR as a voluntary standard (9). In 1991, AAR made it a mandatory standard for all equipment in interchange service, and full compliance by the nation's railroads was required by the end of 1994. AEI allows information such as type of railcar, alphanumeric car identification code, cargo, and weight of shipment to be read and processed automatically by special wayside equipment or readers. These readers interpret and validate equipment identification codes and can also append time and date information to the equipment codes prior to transmission to a host computer or other device.

The manufacturer of most of the tags and readers now being installed on the U.S. railcar equipment fleet claims that the tags can be read over a range of distances, from a few millimeters to 75 meters (235 feet), and at speeds up to 300 kph (180 mph) (10). The accuracy of the system is reported to be near 100 percent and effective under extreme conditions typical of the railroad operating environment, such as electrical interference, dirt, vibration, and inclement weather.

3.1.4 Remote Highway/Rail Intersection Monitoring

Railroad signal departments are faced with the competing demands of maintaining highway/rail intersection signal controllers in working order at all times, and doing so within the constraints of available time, money, and labor. State-of-the-practice methods of highway/rail intersection equipment monitoring rely upon reports from train crews or the motoring public for notice of damaged, defective, or malfunctioning signals or gates. The information is then relayed to the appropriate signal maintainer responsible for the equipment, and in many cases, it may be several hours before the problem can be rectified. In recognition of this problem, several railroads are exploring the possibility of remote monitoring of highway/rail intersection controllers to provide immediate notification if and when an equipment malfunction occurs.

One proposal combines sensor technology for remote monitoring with cellular communications to create a grade crossing health monitoring system. In the event of a malfunction, the cellular communications unit dials a pre-programmed sequence of phone numbers to provide proper notification. Similarly, the signal maintainer would have the capability of calling the unit at any time and from anywhere to obtain a verbal status report on the equipment at the crossing. The Union Pacific, Wisconsin Central, and Burlington Northern Railroads are in the process of implementing Cellemetry Data Service for monitoring alarms at highway/rail intersections. The information will be transmitted to a server operated by the provider of the service and relayed to the control center of the railroad. This type of data service could help eliminate the need for redundant batteries and rectifiers currently utilized at highway/rail intersections to ensure fail-safe operation.

A Canadian railroad is testing the Crossing Supervisory Health System to facilitate more efficient use of labor for maintenance activities and to improve safety at the equipped sites (11). Crossing monitors installed at selected test crossings are linked to a central computer. The central computer interrogates the various locations on a constant basis to inquire about the health of the devices. Any malfunctions which may occur, either before or during a train movement, are identified and reported. The state of Florida is currently implementing a similar system utilizing RF communications in the licensed 900 MHZ frequency range. Health monitoring will be conducted on the entire south Florida rail corridor from West Palm Beach to the Hialeah yard and transmitted to the CSX maintenance facility at Hialeah. With both types of system maintenance, forces can be dispatched expeditiously to the site to perform the necessary repairs and bolster the credibility of the highway/rail intersection signal controllers along the corridor.

The United States Department of Transportation (USDOT) has shown interest in the subject of highway/rail intersection monitoring and malfunction reporting. The 1994 Action Plan mentions the development of a "hardware/software package for automatically receiving and forwarding reports of malfunctions and emergency situations" (4). Accident statistics indicate about half of all train-motor vehicle collisions occur at crossings with train-activated signals and/or gates (11). The reduction in maintenance response time and the data stored during the monitoring process will assist in improving the credibility of these devices.

3.2 INTELLIGENT TRAFFIC CONTROL MANAGEMENT CONCEPTS

With the advent of transportation management centers and the potential for the development of intelligent transportation management associated with a central control point for highway-related surface transportation, a new focus on traffic control has transpired. While the transportation management centers do not have a system as extensive as the railroad infrastructure deployed throughout the nation, they do have the potential to provide information that is much more detailed, with regard to the traffic movements on the highway system, than the railroad can currently provide with regard to train movements.

3.2.1 Automated Enforcement

Automated enforcement technologies have been used on roadways in the United States and extensively in Europe, with the first application originating in the Netherlands. Automated enforcement uses sensor technology to detect violators, then activates a high-resolution camera to obtain photographs of the violation occurring, the violator's vehicle license plate, and in some cases, the driver of the vehicle. The Burlington Northern railroad experimented with an automated enforcement system at a crossing in Jonesboro, Arkansas. This system was extremely effective in reducing the number of violations during activation at the highway/rail intersection location where it was deployed and fostering compliance to highway/rail intersection signals throughout the community. However, jurisdictional issues related to the maintenance of the camera promulgated the removal of the automated enforcement system.

One of the most ambitious automated enforcement programs in the United States being conducted is on the Los Angeles County Metropolitan Transportation Authority's Metro Blue Line between downtown Los Angeles and the City of Long Beach (13). With the enforcement system in use, one of these sites is already integrating ITS technology into the operation of the highway/rail intersection.

The first enforcement system, located in the cab signal territory, utilizes inductive loop detectors imbedded in the pavement within the "protected" area of the crossing to detect vehicles. The detectors are integrated with the signal and gate activation mechanism. The alternate system is located in street-running territory at an highway/rail intersection with no flashing signals or gate arms present to warn motorists or deter them from entering the crossing. Both train and vehicular movements are governed by the street traffic signal controller. In order to activate the camera when a violation occurs, the detectors are integrated with the traffic signal controller. The difference between these two types of systems is in the means of triggering the automatic camera.

Another crossing located in street-running territory is equipped with an AUTOSCOPE video imaging system. The AUTOSCOPE system is a video image processing product marketed by Econolite. This automated concept for enforcement utilizes the AUTOSCOPE system for both train detection and vehicle detection functions. The system is comprised of three components:

- The imaging hardware is an electronic video camera positioned to view both the rail and roadway approaches.

- The video image processor analyzes the video image to determine if a train or vehicle is present.

- Software performs detector programming, viewing of vehicle detections, and street surveillance.

Using interactive graphics, the user can specify the location of "loop detectors" for train and vehicle detection. The "loop detectors" detection lines are digitized on a TV monitor displaying the electronic camera's field of view. As with inductive loop detectors imbedded in the roadway pavement, a detection signal activates the camera to photograph violators when a train is approaching. The system is advantageous because it eliminates the need for inductive loops cut into the street and track circuitry to detect approaching trains, and allows for easy, flexible positioning of detection lines.

TransLink® is in the process of installing an AUTOSCOPE system at the intersection of George Bush Drive and Wellborn Road on the rail corridor testbed located in College Station, Texas. This system will be evaluated for train and vehicle detection capabilities as well as an information source to provide data related to highway/rail intersection and traffic signal interaction during preemption.

In recent studies conducted by the Texas Transportation Institute, violations at highway/rail intersections were evaluated and categorized into three separate areas. These categories included:

- flashing light violations which occurred when the warning lights were flashing and the gate arms were vertical or during the initial two seconds of the gate arm descending,

- typically enforced violations which occurred after the gate arms had been in motion for two second or when the arms were in the horizontal position prior to the arrival of the train, and

- after train violations which occurred after the train departed the site but before the gates were completely raised.

Approximately 47 percent of the violations were in the typically enforced violation category. The flashing light category represented 47 percent of observed violations. The after train category contained 5 percent of the observed violations, with most of the violations at one site. Had that site not been included, the after train category would have had only about 2 percent of the observed violations (14).

The study also indicates that on average, one violation occurs for each gate activation at a gated crossing. For typically enforced violations only, approximately one violation occurs for every two gate activations at an active crossing. During the study, 69 percent of the drivers arriving when the lights were flashing before or during the initial two seconds of the gates moving committed a violation. For those drivers with an opportunity to commit a typically enforced violation, 34 percent did so. When warning times of less than 35 seconds were observed, a relatively low number of violations occurred. When warnings of greater than 35 seconds were observed, considerable variability existed, and higher numbers of violations occurred. The amount of warning time at a highway/rail intersection was found to be a significant factor in the number of violations that could be expected.

Senate Bill 1512, which was passed into law by the 74th Texas Legislature in 1995, required TxDOT to conduct an automated highway/rail intersection enforcement system demonstration project. The demonstration project was conducted to assess the viability of automated enforcement at highway/rail intersections and compiled into a report to the Governor, the Legislature, and the director of the Legislative Budget Board (15). This effort demonstrated the importance of full cooperation between the major players in such an endeavor. The major players in this demonstration project included the agency with jurisdictional authority over the roadway, the railroad, and local law enforcement agency. Correspondence containing educational materials was mailed to the violators, but the legal mechanisms were not established to issue citations. Automated enforcement was recommended as a valuable tool for the reduction of highway/rail intersection violations if the appropriate legal measures could be exercised to allow for the violators to be cited (16). Results of a before and after study indicated that the effects of sending educational materials to motorists recorded as violating the gate arms did not affect the violation rate (14).

3.2.2 Intrusion Detection/Performance Monitoring

The utilization of video technologies as a method of providing advanced notification of potential hazards at highway/rail intersections is becoming more and more prevalent in many rail safety related applications. With the allocation of the Section 1010 funding for high-speed rail improvements, many of the state agencies and railroad entities having jurisdictional authority over the designated high-speed rail routes are exploring various methods of ensuring safe high speed operation. Highway/rail intersections are allowed to remain open if the maximum operating speeds on the corridor do not exceed 110 mph (17) and appropriate measures are implemented dependent on the amount of exposure anticipated at the location. The state of Florida is investigating the use of four-quadrant gated highway/rail intersection installations as a means of reducing exposure on the corridor segment between Orlando and Miami. After exhausting all practical highway/rail intersection safety improvement concepts, they have isolated five highway/rail intersection locations deemed appropriate for four-quadrant gate installations. With the current controversy surrounding the installation of four-quadrant gate installations, the proposed approach is to monitor the performance of the installations utilizing a video surveillance system. The surveillance system will be activated for a fixed amount of time (four minutes) by an electronic eye focused on one of the flashing lights at the intersection. The intent of the surveillance will be to evaluate the effectiveness of the system before, during, and after a train movement, which will facilitate the development of a database that will assist in the calibration of the operational aspects of the system.

The Illinois Department of Transportation is also currently involved in the implementation of high-speed rail in an existing rail corridor between Chicago and St. Louis. The proposed approach on this particular corridor will be to implement high speed operation in increments that will eventually exceed 110 mph. Above 110 mph, the FRA suggests using "positive protection," which frequently includes grade separation structures but also includes devices that will help guarantee non-intrusion of a motor vehicle into the path of an oncoming train (18). At locations where highway/rail intersections will remain at-grade in segments where operating speeds in excess of 110 mph are anticipated, the proposed enhanced warning devices will include a vehicle arresting barrier system. This type of system is designed to actually place an arresting barrier directly in the path of any oncoming motor vehicles. Preliminary proposals include a video monitoring system to assess the effectiveness and reliability of the arresting barrier system. Preliminary calculations indicate that the total elapsed time required for the highway/rail intersection operation prior to the arrival of a train or the advanced preemption needed for operation will be in the two to three and a half minute range. For high-speed rail operations exceeding 125 mph, at-grade highway/rail intersections will not be allowed.

4. TRAVELER INFORMATION

An extremely promising by-product of a system comprised of intelligent highway and rail information is a resource that would provide better information to the end users of the highway system. Providing traveler information at a local level or adjacent to the interaction of the highway and rail networks could significantly reduce the potential for incidence and other safety concerns. A more global or advanced dissemination of information could reduce travel delays associated with rail and highway interaction as well as provide a communication infrastructure by which information could be exchanged that would significantly enhance the safety aspects of highway/rail intersections both from a highway and rail perspective.

4.1 LOCAL TRAVELER INFORMATION EXCHANGE

This type of traveler information exchange is directed toward activities in the immediate vicinity of highway/rail intersections, providing information to the motorists related to any immediate hazard associated with nearby highway/rail intersection activity.

4.1.1 In-Vehicle Warning System

An in-vehicle warning system addressing rail activities is intended to alert drivers approaching a highway/rail intersection to the close proximity of a train. Current in-vehicle warning offers significant potential as an effective median for distributing information to the operator of a motor vehicle. An in-vehicle warning system could be used at both passive and active highway/rail intersections; however, the greatest potential for benefit would be realized at passive crossings where motorists receive no active indication of the approach of a train. Two conceptual designs for in-vehicle warning are under development, referred to as a two-point or a three-point system. A two-point system provides direct train-to-vehicle communication, broadcast by a transmitter on the locomotive to a receiver on the approaching highway vehicle. With a three-point system, the warning message is broadcast from a roadside transmitter or beacon.

Information elements and warning messages that should be broadcast to drivers by an in-vehicle warning system have not been clearly defined to date. The simplest approach would involve notifying the driver that a train is approaching or that an upcoming highway/rail intersection is blocked by a train. Another alternative would be to inform the driver of the train's approach, the direction from which it is approaching, and an estimate of its arrival at the intersection. This alternative would require three types of information:

- Train position (variable) with respect to the crossing (a fixed point),
- Train speed, and
- Direction of travel of the train.

An estimated arrival time for the train could be generated by either the non-intrusive techniques being investigated through second generation technologies or from third generation technologies utilizing global positioning information.

4.1.2 Highway/Rail Intersection Status/Health Monitoring

The current efforts by some railroads to perform continuous remote monitoring of highway/rail intersection system health and status could provide secondary benefits to highway traffic operations personnel. The primary benefits would extend to emergency response services and the transportation management system in urban areas, especially those that monitor and control congested highway corridors.

A highway/rail intersection monitoring system would have the potential to provide two useful types of information to a transportation management center. The transportation management center would be able to determine the activation status of highway/rail intersection safety devices. This information would allow the transportation management center to track train movements and their progress, and take action to alleviate the effects upon traffic congestion on intersecting and adjacent roadways. Possible responses would involve the further development of first generation technologies for the temporary adjustment of traffic signal phasing and timing, and the implementation of lane use and turn restrictions through dynamic lane assignment and dynamic message signs. The information could then be transmitted to emergency service personnel, police, fire, and ambulance services to facilitate routing which avoids blocked crossings and thereby optimizes emergency response time. Similar actions could be implemented by the transportation management center in the event of highway/rail intersection signal malfunctions.

4.2 ADVANCED TRAVELER INFORMATION EXCHANGE

This type of traveler information exchange is directed toward the development of traffic management activities that could provide information to the motorists and to the railroad well in advance of any potential conflicts at highway/rail intersections.

4.2.1 Intrusion Detection

Video image processing may offer the potential for early detection of obstructions at highway/rail intersections. Early detection of stalled, disabled, or trapped vehicles blocking the intersection and in the path of an oncoming train would allow information to be transmitted to the railroad so the train could be stopped, rerouted, or required to move at restricted speed in anticipation of track blockage (17).

The potential benefits of such a system were illustrated by two tragic train-motor vehicle collisions in Florida in 1993. In the first incident, a tractor semi-trailer hauling gasoline was negotiating a congested highway work zone and entered the crossing. When an Amtrak consist approached the intersection and the highway/rail intersection device activated, the truck was trapped between vehicles to the front and rear, and was struck by the Amtrak passenger train. The ensuing explosion and fire claimed several lives. In another highly-publicized incident, a tractor-trailer hauling an 82-ton gas turbine generator became high-centered on a humped crossing near Kissimee, Florida. Attempts to notify railroad authorities of the blockage were unsuccessful, and an Amtrak passenger train collided with the truck, injuring 58 passengers. An intrusion detection system may have been capable of intervening in the operation of the passenger trains involved in these incidents in time to avert a collision (19).

The effectiveness of an intrusion detection system is in part a function of train stopping distance. Train speed, weight, the braking system, horizontal and vertical track alignment (curvature and grade), and environmental conditions all factor in to determine the actual stopping distance of a train. The stopping distance defines the minimum distance from the crossing at which successful intervention in the train's operation would be needed to avoid a collision with a stopped, stalled, or disabled vehicle (19). For each highway/rail intersection, a critical train stopping distance may be calculated based upon the train operating characteristics and other factors identified above. If the distance from the train to the vehicle exceeds the critical stopping distance, intervention in the train's operation will successfully halt the train before an accident occurs. If the distance from the train to the vehicle is less than the critical stopping distance, a collision will be imminent, although intervention would have the potential to lessen the severity of the collision.

5. INTELLIGENT TRANSPORTATION SYSTEM MANAGEMENT

The challenges associated with an ATCS, PTS, AEI, highway/rail intersection status and health monitoring, and automated enforcement could be minimized with stronger communication between railroads, state and local highway authorities, and equipment suppliers. Some unanticipated institutional barriers have constrained the development of rail-related ITS improvements. The further development of the integration of rail information into the transportation management system could be enhanced by expanded research related to proof-of-concept activities.

Historically, the only information exchange between railroad and roadway entities has been transmitted from the highway/rail intersection signal to an adjacent traffic signal. The following diagram illustrates the current information exchange, what is envisioned as the next or second generation exchange of information, and finally a full blown ITS exchange.

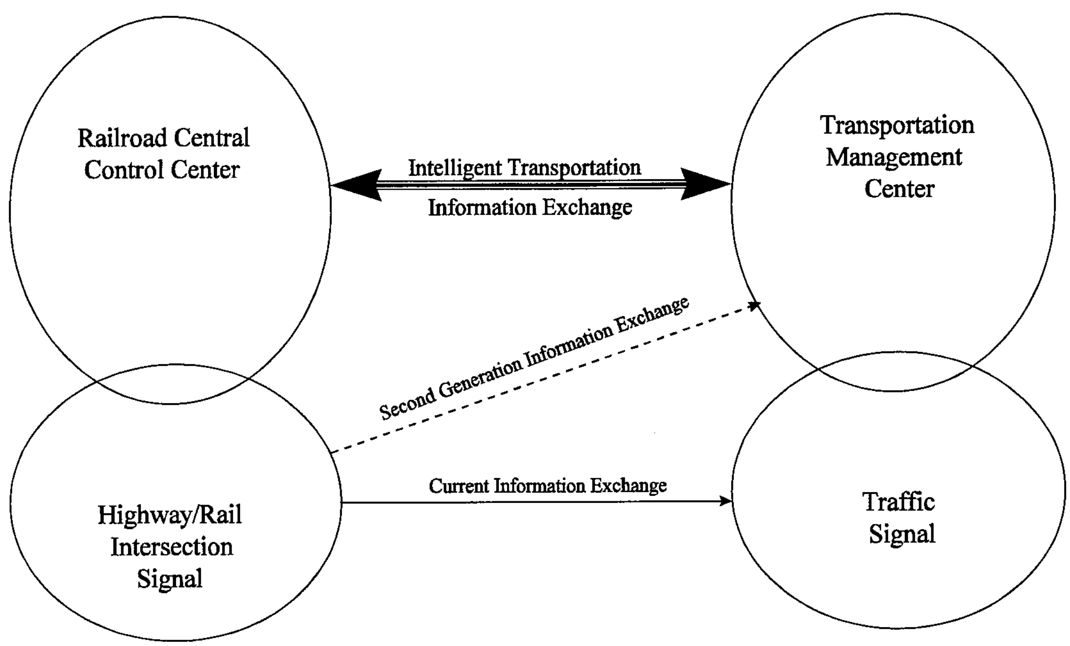

Figure 1. Information Exchange Between Modes

When evaluating the entire intelligent transportation concept in the past, there has sometimes been a tendency to lose sight of the ultimate objective of the efforts being implemented by any of the entities associated with surface transportation modes. Traveler information exchange concepts provide the opportunity to disseminate information to the ultimate end users and there by play a major role in the overall functionality of the proposed ITS. The following diagram illustrates the concept of traveler information exchange at both the local and global levels.

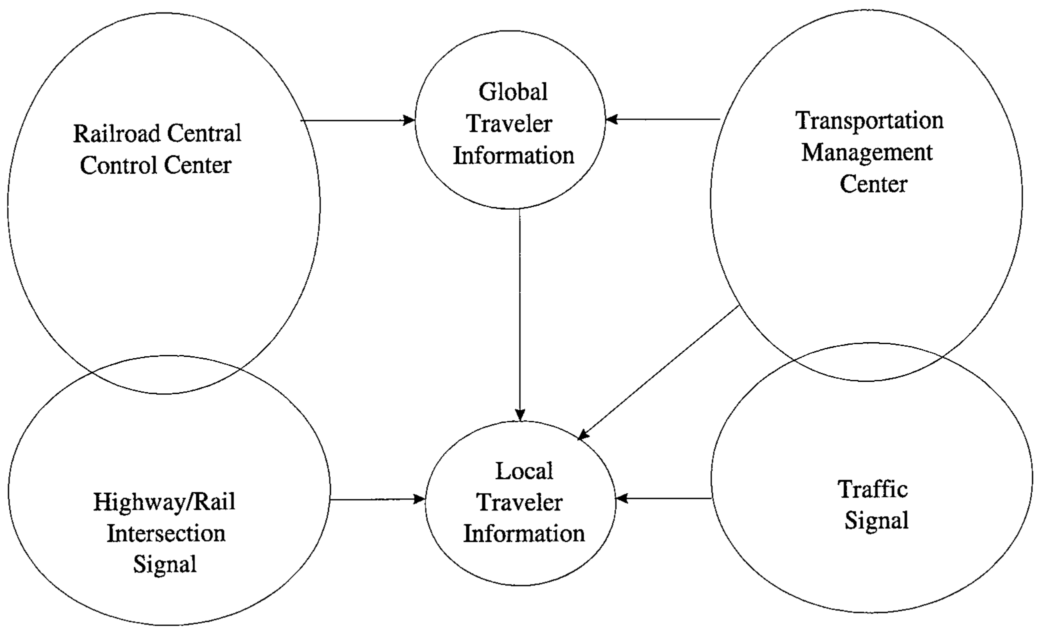

Figure 2. Traveler Information Exchange

6. FINDINGS

The current state-of-the-practice for rail integration remains a somewhat archaic method of providing information to the traffic signal controller from the highway/rail intersection signal controller. The concept of ITS should focus on developing methods of establishing an integrated surface transportation system with all of the various subsystem components included. As we explore the possibilities associated with rail integration, one of the primary objectives should be to formulate practical methods of implementing ITS concepts within a realistic time frame. Developing the basic applications of a system that may not be widely deployed for another 10 or 15 years may be desirable but will not address the current problems associated with rail integration. The methodologies associated with rail integration need to be developed for the various stages of ITS deployment that are anticipated. Continued development in the various stages of rail integration can be categorized based on the anticipated technologies that can be expected to be major components of the integration effort.

6.1 FIRST GENERATION TECHNOLOGIES

The continued refinement of integration activities associated with current state-of-the-practice activities will be important in the near term for many locations throughout North America. With the current institutional issues associated with rail integration, the utilization of highway/rail intersection and traffic signal interconnects will remain an important component of highway/rail operational and safety issues. The continued use of simultaneous preemption and the expanded use of advanced preemption intensifies the need for new methods of utilizing the current train location information more efficiently. Some conceptual ideas that are relevant to these activities include the development of better traffic signal transition sequencing when a preemption call is received, and better transportation management strategies when returning from preemption.

Recent research has focused on improved means of traffic signal controller response to a preemption input. Current preemption treatments may curtail both vehicular phases and pedestrian indications in an attempt to reach the track clearance phase (i.e., the signal phase which clears motorists from the rail crossing) as quickly as possible. The current practice, allowed by the *Manual on Uniform Traffic Control Devices* (MUTCD) (20), is to truncate the pedestrian signal phases to one second upon the initiation of preemption associated with rail movements. Improved preemption strategies, which will rely on advanced detection of the approach of a train whether by first, second, or third generation technologies, are needed to better manage time and signal control more efficiently and enhance safety prior to the arrival of the train at the highway/rail intersection.

The development of enhanced phasing strategies when returning from railroad preemption shows promising potential in that a multitude of phasing patterns could be established. The correct phasing pattern for returning from preemption under a specific set of conditions could be programmed into the traffic signal controller based on information stored from previously simulated replications of similar conditions. An extended application of the current simulation practices developed specifically for railroad preemption could be a useful tool in minimizing disruptions associated with a train movement at a preempted traffic signal. This application should be focused on optimizing highway/roadway operations when returning from railroad preemption.

When the preemption event terminates, in most cases, the controller must use a transition algorithm to adjust the offset of the phase sequence. The two basic approaches involve either lengthening or shortening one or more phases until the offset of the signal is in step with the coordinated system. Preliminary research at the Texas A&M Research Center of Excellence has been conducted on the operational impact of alternative resynchronization algorithms. That research included an evaluation where a series of preemption events were introduced at various points in the coordinated cycle and the performance of alternative cycle transition algorithms evaluated. The basic outcome of that research suggested that utilizing simple short-way algorithms is **not** the most efficient approach. However, once again the reader is cautioned that the above methods have not been fully developed for actual field application, and further study is warranted.

6.2 SECOND GENERATION TECHNOLOGIES

The primary objective of this initiative is to develop the exchange of information between the various modes of the transportation system. These types of integration efforts are focused on techniques that can be utilized in the interim period or the period of time prior to the substantial deployment of third generation or global positioning satellite based or similar technologies. These particular integration techniques utilize a mixture of traffic detection technologies adapted for train detection, and new and emerging detection, communication, and data processing technologies. The current institutional issues associated with rail integration have steered the development of second generation integration methodologies toward a more non-intrusive approach. Non-intrusive rail detection is directed toward the placement of detection devices capable of train presence and speed detection from physical locations that are not on railroad right-of-way. These techniques eliminate the need for cooperation from the railroad during rail-related ITS activities.

Rail integration utilizing advanced capabilities of standard railroad highway/rail intersection equipment is another area of interest that illustrates potential for more advanced train detection. The development of this type of integration methodology would speed up the deployment of a rail-related ITS infrastructure because of the significant number of highway/rail intersection installations currently deployed on the rail network throughout the nation. Preliminary observations indicate that a reasonably accurate estimated time of arrival and departure of a train at a highway/rail intersection equipped with a prediction controller can be obtained. One shortcoming of utilizing information from this type of device is determining the direction of travel of the train. However, in corridor segments with multiple installations of this type, the direction of travel could be determined by evaluating a series of activations, with ETA and ETD updates being calculated at each highway/rail intersection equipped with a prediction type detection controller. The initial research associated with this type of system would have to be conducted as proof-of-concept developments because of the current institutional barriers associated with highway/rail intersection signal controllers.

One in-vehicle warning technology that shows potential for a moderately timely deployment is the Emergency Radio Data System (ERDS). This system also illustrates great potential in that the message is transmitted to an ERDS equipped radio regardless of the current programming the motorist is utilizing. The message is transmitted via audio and, in some cases, displayed via light emitting diode (LED). At least one major automobile manufacturer in the United States has indicated that this radio equipment will be offered as standard equipment in the near future.

As with any in-vehicle warning system or ITS concept the overall deployment of this type of system is the limiting factor associated with their effectiveness. It is anticipated that the ERDS will have greater potential for large scale deployment than any of the alternative systems currently being proposed, based on the fact that a special device will not have to be purchased by the motorists to receive the in-vehicle warning messages. Questions arise as to how effective a system of this nature will be if the motorist actually has to purchase a component of the system to receive the safety-related benefits. Currently, the most common deployment of this system is the three-point concept related to in-vehicle warning where a transmitter is placed at a particular highway/rail intersection and traffic signal. The ultimate deployment of this type of system would be a two-point configuration where the transmitter is actually mounted on the locomotive and the message transmitted to vehicles along the entire rail corridor. This would allow in-vehicle messages to be transmitted to motorists at all highway/rail locations regardless of the type of warning equipment at that location. Current institutional barriers have prohibited this activity to date, thereby creating the need for a proof-of-concept approach to additional research.

6.3 THIRD GENERATION TECHNOLOGIES

Train location information generated from a global positioning satellite system appears to be the detection concept of the future. Several companies have embarked in the development of this type of system. Current indications are that PTS, PTC, ATCS, or some other global positioning satellite related concept will be the next generation of methodologies utilized to establish train detection/location. These concepts show great potential for expanding capabilities in the ITS theater and may be the answer that railroad and transportation safety engineers have been in search of for decades. The actual time frame associated with the deployment of this type of system is, once again, the limiting factor.

Currently, the development of a wayside highway/rail intersection control device that operates in conjunction with a central server-based PTS system illustrates great potential for global and local traveler information exchange and traffic control. Manufacturers currently involved in the development of a global positioning satellite train location/control systems include: G E Harris, Harmon Industries, Safetran Systems, Siemens, Rockwell International, and an Italian firm, General Consulting and Engineering. A global positioning satellite based train location/control system, when sufficiently deployed, will have a significant influence on the management of train operations and safety-related practices. The interaction of this system with current transportation management practices will be dependent on the development of the supplemental safety and communication infrastructure. The overall deployment of this type of supplemental system would be desirable but will rely heavily on the amount of research and development directed toward these efforts in the future.

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