Innovations Deserving
Exploratory Analysis Programs

High-Speed Rail IDEA Program

ENHANCED PROXIMITY WARNING SYSTEM (EPWS) FOR LOCOMOTIVES

Final Report for High-Speed Rail IDEA Project HSR-05

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October 1997

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ENHANCED PROXIMITY WARNING SYSTEM (EPWS) FOR LOCOMOTIVES

IDEA PROGRAM FINAL REPORT
CONTRACT NO. HSR-05

Prepared for
the IDEA Program
Transportation Research Board
National Research Council

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October 30, 1997

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EXECUTIVE SUMMARY

The primary focus of the "Enhanced Proximity Warning System" (EPWS) is to provide a cost effective means to improve safety of railroad operations, with the ability to implement on an incremental, building block approach. The main safety objective of EPWS is for prevention of train collisions, but other safety functions, such as compliance with operating rules, and verification of train braking capability can also be addressed with the system..

The U.S. railroad industry has been active in evaluation of new radio-based train control and protection systems over the past decade. Most of the systems developed and pilot tested to date have required a significant infrastructure investment, with both trackside and dispatch office hardware and systems. Examples are the Association of American Railroad's "Advanced Train Control System" (ATCS) initiative (began in the mid 1980's), as well as the current joint Union Pacific/Burlington Northern Santa Fe "Positive Train Separation" (PTS) pilot projects. In both of these systems, a fairly complex central control office is required, with a wide area two-way data radio system, to provide coverage of the target routes. These systems are capable of providing close to full collision avoidance protection. However, as a highly centralized approach, they tend to require implementation on a wide scale and require a substantial data radio communications system and trackside equipment infrastructure investment. Neither ATCS or PTS systems have been implemented beyond pilot projects to date, largely due to the large front end costs, and related difficulty for railroads to cost justify the investment.

Pulse Electronics had been working with Burlington Northern (BN), prior to their merger with Santa Fe, on two development initiatives which form the basis of EPWS. The first was the "Rail Navigation System" (RNS), which focused on providing the ability for locomotives to automatically locate themselves against an on-board track database, without the need for any track or ground infrastructure additions. Use of U.S. military Global Positioning System (GPS) satellites was a key part of the navigation system, but needed to be supplemented by other sensors to permit accurate location and track 1/2 determination.

A second initiative on BN was for development of a "Proximity Warning System" (PWS) which was based upon shared use of one of the end-of-train (EOT) monitor system frequencies to establish direct locomotive-to-locomotive data communications. The radio and channel use for PWS was designed in a manner which protected EOT operation as the primary user of the channel, while using the spare channel capacity for train-to-train data exchanges. This communications link was used to exchange GPS-based location references, speed, and direction information between trains. Each locomotive could then compute the distance and relative direction of other trains, for warning the engineer of potential conflicts. PWS is suitable for light traffic areas, with few tracks, but was recognized as limited for higher density applications.

EPWS represents a merging of RNS and PWS. This allows location information to be exchanged between trains using track ID and milepost references as opposed to latitude/longitude references as in PWS. The on-board track database, as part of the RNS sub-system, also allows implementation of a number of safety functions which are not dependent upon the radio data communications between trains.

Hardware implementation of the EPWS system was based upon adaptation of existing Pulse designs, with custom interfaces and software. The major part of the IDEA program effort was related to software development and field testing. Three BNSF locomotives were equipped, with field testing on the Topeka subdivision. The initial locomotive was equipped in November 1996, and testing with three trains was conducted in August and September 1997.

The BNSF involvement in the project was critical, and lead to a number of additional safety functions relating to crew alertness. The system as developed is able to provide safety enhancements within a single train, using the on-board track database and location determination capability even without the radio communications functions.

The base EPWS implementation, in concept, is an "open loop" warning system as opposed to a "fail-safe" train control system. However, there are growth paths which allow "closing the control loop" by adding data links to the dispatch office. This supports an incremental approach for expanding to "Positive Train Control" functions, where and when needed.

Pulse Electronics and BNSF are planning to follow-up the past effort with an expanded pilot project in Southern California. This will allow further system refinements and productionization, to allow consideration for widespread application.

ENHANCED PROXIMITY WARNING SYSTEM (EPWS) FOR LOCOMOTIVES

DOT-IDEA Project, Contract No. ITS/RR-39

Robert C. Kull, Director, Advanced Technology, Pulse Electronics, Inc., Rockville, Maryland

IDEA PRODUCT

A means has been developed to improve the safety of train operations based upon addition of locomotive hardware, with a minimum of ground hardware required. A test installation was made on three Burlington Northern Santa Fe (BNSF) Railway locomotives, operating on the Topeka (Kansas) sub-division. The BNSF involvement lead to additional EPWS system functions, beyond that originally planned, some of which were implemented in test form. The results of the IDEA project will be used to implement an expanded pilot project on BNSF in Southern California, with 10 locomotives in captive service.

CONCEPT AND INNOVATION

The concept of EPWS is based upon integration of two sub-systems:

(1) Rail Navigation System (RNS): Locomotive computer system with internal GPS receiver, gyro, and axle generator interface, with ability to determine location and track ID against the on-board track database.

(2) Proximity Warning System (PWS): Shared use of the locomotive to end-of-train (EOT) radio channel to establish direct train-to-train data communications on a local area basis.

Trains periodically broadcast their current track ID, location, direction, speed, and routing plans, which are received by other trains in the area. A color graphics engineer display provides an illustration of its own train, as well as other trains in the area, against the track profile.

The EPWS system is able to advise of potential movement conflicts based upon comparison of data among trains in the area. The action to be taken in event of a track conflict is based upon railroad operating rules, but would normally be to establish contact on the voice radio to check and compare current operating authorities.

The uniqueness of the EPWS concept is to provide an economical means for providing increased safety and protection from train collisions, without requiring significant ground infrastructure additions, or new central control office systems. This requires determination of train location on an accurate and reliable basis, without need for track transponders or differential GPS correction stations. It also requires a RF spectrum efficient means of establishing communications between locomotives within the same area, using existing radios and railroad channel allocations.

FIGURE 1 System Overview

The above figure illustrates the basic EPWS concept. The only ground infrastructure requirements for the base EPWS system are for radio repeater units to extend coverage in selected poor coverage areas. This would typically be limited to mountainous areas, and was not required for the pilot test area in Kansas.

IDEA PROJECT INVESTIGATION AND PROGRESS

The locomotive hardware was designed based upon adaptation of existing Pulse Electronics products. The hardware elements and revisions in support of the EPWS project were:

(1) On-board Computer: Based upon the Pulse Armadillo™, which is a ruggedized 486-based computer designed for locomotive applications. (Refer to Fig. 2 on following page.) The GPS receiver, gyro (angular rate of motion measurement), axle generator interface (locomotive wheel turns measurement), trainline interfaces (forward/reverse), and penalty brake interface were added within the Armadillo™ unit.

(2) Engineer Display: A color graphics (VGA) display is driven from the Armadillo™, with function keys for input against soft screen menus. This display has very bright backlighting for sunlight readability.

(3) PWS Communications Unit: A Pulse TrainLink™ locomotive control unit with PWS capability was re-programmed to provide EPWS communications functions, while also performing the normal EOT monitoring and control functions.

(4) Support Hardware: Mounting brackets, cabling, and a GPS antenna were provided to support the locomotive installations.

FIGURE 2 On-board Computer

The first set of locomotive hardware was installed in November 1996, and was used to support the RNS portion of software development, before the communications functions were added. Development was started using pre-prototype RNS software, which was substantially improved and upgraded as part of the EPWS project. The effort focused upon improvement of the algorithms used to determine track location, as well as changes of track ID through switch machines.

During operating reviews with BNSF, a number of suggestions were made to add functions to the on-board system. These suggestions resulted in addition of several safety enhancements related to crew alertness. Additional EPWS functions based upon BNSF ideas included:

(1) Alert upcoming highway crossings, with the need to sound whistle warnings.

(2) Alert upcoming signals, with menu prompts to enter signal aspect information via the display.

(3) Advise of upcoming permanent track speed restrictions.

(4) Monitor and alert of overspeed conditions, or failure to comply with signal aspect data as entered.

The EPWS system includes a penalty brake interface which would allow the train to be automatically brought to a full stop in the event of non-compliance or detection of defined safety violations. While the hardware was designed, it was decided to not include this interface in the test installations, to avoid the risk of undesired train stops during testing.

Addition of the crew alertness features extended the time for software development and field testing of the standalone system, before additional locomotives and the communications functions were equipped. This functional addition illustrated the potential safety value of providing individual locomotive systems, on an incremental basis, even before the data communications functions are provided.

Installation of an additional two locomotives took place in July 1997. Field testing on trains with the PWS data communications functions were conducted in August. The initial tests revealed a number of software related problems which were rectified on subsequent tests.

FIGURE 3 Locomotive Cab with EPWS Display

The above photo (Fig. 3) shows the placement of the EPWS graphical display unit, to the left of the engineer position. A swivel mount was used to allow changing the rotation and angle of the display for optimum viewing for the locomotive engineer, as well at test engineers. The TrainLink™ PWS unit is mounted to the right of the graphical display, and was used to confirm PWS data radio communications, as well as the normal EOT monitoring functions. The standard locomotive speedometer is shown on the right, and was used to check the EPWS measured speed (using GPS and axle generator) against the normal axle generator only based speed measurement.

An example of the engineer display is shown on the following page (Fig. 4), in grayscale format. Colors provide clearer readability on the actual display. The display shows the “home train” (BNSF 2700) on the mainline heading westbound (towards Emporia), meeting an eastbound train (BNSF 2886) stopped in the siding at Noria. The dark part of the train shows the length as entered by the engineer upon system set-up.

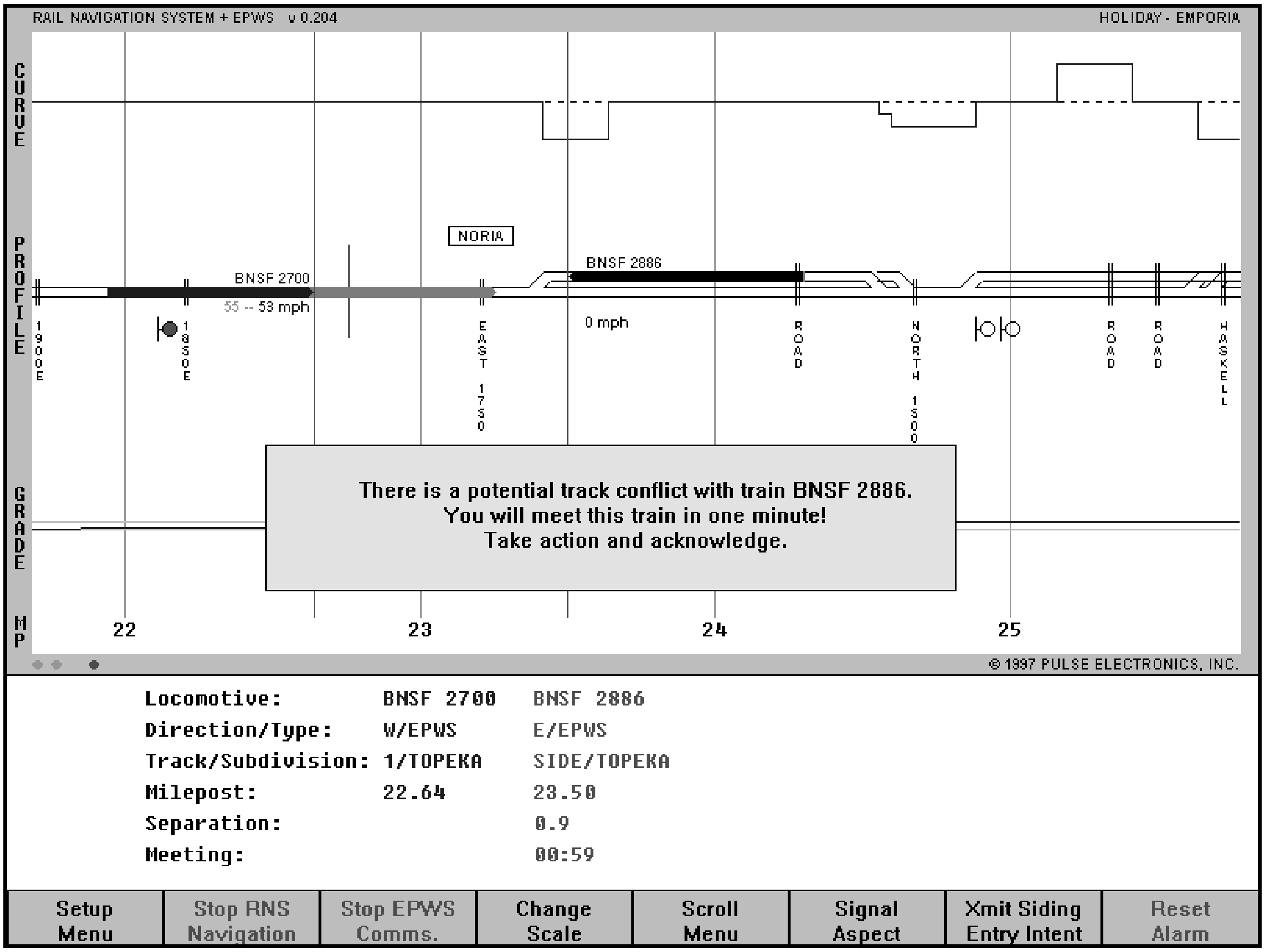

FIGURE 4 EPWS Engineer Display

The shaded area in front of the moving train shows the projected "full service" braking distance to a stop. This is calculated based upon the train speed, length, and average grade over the braking distance. The projection as provided is conservative, and emergency braking would typically be possible well within the projection. A separate shorter vertical line within the shaded braking distance curve illustrates the distance required to slow down to the next track speed restriction point.

The track layout is shown in the center horizontal line on the screen and includes the following features:

- Track sidings
- Names of towns, sidings
- Switch turnouts off the system (industrial tracks, etc.)
- Milepost markers
- Highway crossings
- Signals
- Speed restriction markers
- Misc. special features, such as bridges, streams

The top horizontal area illustrates track curves. The graphics conveys the degree of curvature, duration, and direction.

The bottom horizontal area illustrates the track grade. The amount of grade, direction, and grade change points can be easily recognized. (Although the example shown is relatively flat.)

Below the graphical track display key information for both trains is provided in tabular form. This includes current track ID, milepost referenced location, separation distance, and projected time to meeting.

Warning messages are provided three minutes prior to a projected meet, and again at one minute before a meet (as shown in the example). Each of these message displays are accompanied by an audible alarm. Alarm messages are to be acknowledged by pressing the "alarm reset" key (far right function button). Failure to acknowledge within a set time can be used to automatically apply the penalty brake.

Logical conditions for providing alarms, the engineer actions required, and penalty braking conditions can be changed to suit different railroad operating requirements. For example, in the example as illustrated in Figure 4, since the opposing train is confirmed in the siding track, it may not be necessary to provide an alarm. However, it may also be desired to alarm all opposing moves in order to insure crew alertness and confirming voice communications between train crews.

Crew alertness alarm messages are also provided in approach to highway crossings (acknowledged by sounding whistle) as well as signals. A function key is provided to bring up a signal entry menu to allow "calling the signals" into the EPWS system. This provides a record of engineer response to signals, as well as allows enforcement relating to the signal aspect as entered.

A separate function key is provided to allow the engineer to advise of intent to enter the next siding. This can be used to confirm operating intentions for normal train meet moves. However, this information is over-ridden if the on-board system does not detect a movement into the siding track.

Additional menu buttons are provided to allow changing the scale of the track display (Fig. 4 is the middle scale), as well as to scroll the display left and right to view other train positions or track data.

Field Testing

The logistics of multiple train testing were difficult, as they were on normally operated trains, which were planned for meet/pass movements. In the August testing, only two trains at a time could be arranged to be within radio range of each other. This did not afford the opportunity to complete field testing with all three trains within the same RF area at the same time.

RF communications coverage was shown to be within expectations, without need for repeater units. Initial data communications was typically achieved within a distance of about 5 to 6 miles, with consistent coverage within 3 miles. This is sufficient for the operating philosophy as envisioned, in which only a single message is needed to provide a warning to each crew.

Following the August field tests, it was decided to take one of the locomotive sets of equipment, and install it in BNSF offices in Topeka, to act as a "pseudo locomotive" to support easier demonstrations and testing. This allowed easier arrangements to get two additional locomotives in the same area at the same time, to test three sets communicating with each other.

Tests of the "3 locomotives" configuration were run in September, which revealed a software error caused the display to alternately show each of the other two locomotives, instead of both together. This error was found and corrected following the tests.

BASE TECHNOLOGY DESCRIPTION

The base technology for EPWS consists of the Rail Navigation System (RNS) and the means of sharing the EOT radio for establishing train-to-train communications. An overview of the implementation of each of these enabling sub-systems is provided in this section.

Rail Navigation System

EPWS navigational computations were designed to be multi-modal. This recognizes the fact GPS measurements are easily interrupted by geography or man-made structures, and on-board sensors and detectors may fail for a variety of reasons. The navigation computations use the best inputs available.

There are two major portions to the navigation computations: coarse navigation and fine navigation.

Coarse navigation finds one or more points that are within a certain distance of the reported GPS latitude and longitude. All that is necessary to perform coarse navigation is the locomotive's current latitude and longitude values, as received from GPS. Coarse navigation is only accurate to within approximately 100 meters and is insufficient to determine if a parallel siding to the main track has been taken.

Fine navigation improves on the accuracy of coarse navigation by matching the location of curves in the database to sensed curves. The fine navigation makes use of the internal gyroscope and axle generator interface as well as the GPS latitude and longitude. At each iteration, the fine navigation algorithm computes a new location based on the old location plus heading and distance changes. This new location is correlated with the track database to eliminate any received sensor noise. Once the location is determined with good accuracy, the fine algorithm continues to navigate down the track using the new established location as the next starting point:

New absolute position = previous absolute position + relative motion

The relative motion of the locomotive is a combination of angular heading movements and distance movements.

The distance that the locomotive has moved since the last calculation can be determined in three ways:

(1) Axle counts from the axle generator

(2) Distance between consecutive GPS lat/long points

(3) GPS speed times time interval

The heading change of the locomotive may also determined in three different ways:

(1) New GPS heading minus Previous GPS heading

(2) Gyroscope detected angular changes

(3) Vector between consecutive GPS lat/long points

The above sensor inputs are weighted with regard to resolution and accuracy and are combined to best determine an exact track position. Unreasonable, failed or unavailable sensor readings are removed from the calculations.

Communications System

Standard North American EOT systems, following the Association of American Railroads (AAR) standards, are based upon two separate frequencies:

EOT to Locomotive: 457.9375 MHz
Locomotive to EOT: 452.9375 MHz

The initial EOT applications in the U.S. were one way systems, using the 457.9375 frequency only. The communications scheme was basically to transmit when status changes were to be reported (such as brake pipe pressure changes), plus approximately once per minute for current status updates.

The second channel was introduced for 2-way EOT operation, where the second channel provides a means for the locomotive to send an emergency brake command to the EOT. This is to provide an added means of braking the train in the event of a brake pipe obstruction within the train, restricting the ability to apply braking only from the head end. In addition to emergency applications, the locomotive to EOT channel is used for periodic communications checks (once per 10 minutes) and for linking procedures at time of train departure.

Both EOT to locomotive and locomotive to EOT RF communications operate without any means for channel contention control. In other words, each transmission is made without needing to check or coordinate with other EOT units. Field experience has shown this to be adequate, relative to the density of train traffic, shortness of messaging, and average messaging rates. This is also aided by the system design, such that continuing status changes (such as brake pipe reductions) and critical commands (such as emergency brake requests) result in multiple message repetitions. In practice, EOT systems can perform their intended functions with relatively low messaging success rates. With EOT systems, a 50% message success rate would provide adequate operation, while this would not be acceptable for most conventional communications systems.

The overall channel use for locomotive to EOT functions is very small, and was therefore seen as a resource which could be used for EPWS applications. A key design criteria for EPWS was to insure there would be no material impact to the primary use of the 452.9375 MHz channel for EOT functions. This was accomplished by the following means:

(1) *CSMA:* Add carrier sense multiple access capability to locomotive units to check for a clear channel prior to transmitting. CSMA performs best with a very high attack time radio, to limit the "window of vulnerability" from when a clear channel is detected and a transmission is made. The Pulse designed radio provides a 2 ms transmit attack time to support effective CSMA operation. (This compares to typical radio attack times of 20 to 50 ms.) CSMA also allows dynamic adjustment of EPWS transmission rates to manage current channel loading. For example, in high density areas - such as near yards - the EPWS messaging rate can be reduced to maintain the RF channel average utilization approximately constant.

(2) *Short Message Lengths:* The EOT data modem operates at 1,200 bps, using MSK (minimum shift keying) modulation. In addition, very long synchronization is used to accommodate older modem techniques. This results in typical locomotive transmit message lengths of about 400 ms. EPWS messages are based upon using a 4,800 bps GMSK modem (gaussian minimum shift keying), with more compact encoding. This allows EPWS messages to be approximately 70 ms in length.

(3) *Integrated LCU:* The EOT and EPWS Locomotive Control Units systems are integrated, based upon having two receivers and shared use of the 452.9375 MHz transmitter. EOT transmissions are given priority over EPWS use, and can also benefit from the CSMA channel checks. Each receiver (one for EOT and the other for EPWS) has its own modem and microcontroller to allow simultaneous reception of both EOT and EPWS messages.

The overall loading of the locomotive transmit channel, performing both EOT and EPWS functions, can be maintained approximately the same as the current loading of the EOT transmit channel. Locomotive to EOT messaging reliability can also be improved based upon the use of CSMA, which is not possible with standard LCU's.

Implementation of the test systems for the EPWS project was based upon modification of standard Pulse TrainLink LCU's with a 452.9375 MHz receiver, GMSK modem, and EPWS microcontoller. Circuitry was provided to allow switching the EOT and EPWS modems to the shared transmitter.

PLANS FOR IMPLEMENTATION OF IDEA RESULTS AND PRODUCT

The Topeka test area as selected was convenient for the initial IDEA development field testing as performed. However, BNSF is not able to easily hold locomotives captive to this area, and the traffic is not as heavy as would be desirable for a larger scale pilot project. Therefore, BNSF is planning an extended pilot test to be conducted in Southern California, with 10 locomotives to be equipped for EPWS operation.

The next step, with the expanded pilot project, is planned to bring the EPWS system to a commercial product level. This will result in productionization of the hardware and software as needed to support large scale implementation.

A number of further system enhancements are planned, and the display screens are likely to be modified following further reviews with operating personnel. Areas which are expected to be addressed in future systems include:

(1) Integration of end-of-train monitoring engineer interfaces to the EPWS display screen.

(2) Additional crew alertness functions to insure compliance with operating rules, with event recorder integration.

(3) Train braking performance monitoring, with alarms of deficiencies and adaptive braking performance predictions.

(4) Locomotive to dispatch office data interactions to improve train meet/pass planning, fuel efficiency, and safety.

Additional functions are expected to be added following the experience to be gained from initial applications.

ACKNOWLEDGMENTS

The critical contributions of BNSF Railway to the EPWS development project are acknowledged, with particular thanks to Mr. Nicholas C. Marsh, Assistant Vice President, Technical Research and Development and Mr. Paul K. Gabler, Senior Engineer, Technology Development.

BNSF delivered a paper titled “Enhanced Proximity Warning and Crew Alertness System” to the Air Brake Association in Chicago, Illinois on September 15, 1977. This paper provides additional details on the IDEA project, including discussion of braking predictions using the EPWS on-board database information. This paper is provided as an attachment.

October 30, 1997

ENHANCED PROXIMITY WARNING AND CREW ALERTNESS SYSTEMS

ABSTRACT

Burlington Northern Santa Fe has joined with Pulse Electronics to develop and test a locomotive-based proximity warning and crew alertness system. The system was developed in response to growing concerns in the railroad industry about the need for effective collision avoidance systems. The design approach achieves success without requiring any additional ground or office infrastructure. A description of the various position tracking and crew alertness features are presented, and the braking implications are discussed.

INTRODUCTION

In recent years there have been several railroad accidents where two trains collided with each other. This has led to growing interest among the railroads, as well as federal and state agencies about the possibility of developing and implementing an effective collision avoidance system. Several developmental efforts have been initiated, including Advanced Railroad Electronic Systems (ARES), Advanced Train Control Systems (ATCS), and Positive Train Separation (PTS) - all of which have the ability to prevent train collisions.

Pulse Electronics and Burlington Northern Santa Fe joined together to develop and test yet another concept - the AEnhanced Proximity Warning System@ (EPWS)/@Enhanced Crew Alertness System@(ECAS). A prototype has been tested on the BNSF Topeka subdivision. The EPWS system provides a means to determine locomotive location and track ID, against an onboard database. Navigation inputs are received from a GPS receiver, odometer, and gyro (rotational velocity). This location information is then transmitted to all nearby EPWS-equipped locomotives using the end-of-train radio frequencies. The position, speed, direction, and intentions of nearby locomotives are presented on a color display located on the cab console. Additional safety features were later built into the EPWS system which enforce that the crews operate in compliance with the railroad=s operating rules. Collectively, these safety enhancements are known as the AEnhanced Crew Alertness System@ (ECAS).

In comparison to the other Advanced Railroad Electronic Systems (ARES), Advanced Train Control Systems (ATCS), and the Positive Train Separation (PTS) systems, the EPWS/ECAS system achieves all of its functionality without the need for a centralized communication or office system. All data communications are directly between locomotives, allowing a significant advantage in the initial implementation cost, effort, and schedule, and in the long-term reliability.

SYSTEM DESCRIPTION

Required Hardware

The EPWS/ECAS system consists of three new hardware components, developed by Pulse Electronics:

1) Armadillo ruggedized onboard computer, with internal GPS, gyro (rotation detection), axle generator (odometer) interface, locomotive reverser interface, and penalty brake control. The Armadillo contains the software program and track data which perform all of the EPWS/ECAS functions.

2) Engineer Display with 6.25" color LCD, sonalert beeper, and eight discrete function keys. The Engineer display is the sole man-machine interface for the EPWS/ECAS system.

3) Proximity Warning System (PWS) unit. The PWS is actually Pulse=s standard TrainLink End-of-Train locomotive control unit, with a modification to allow EPWS/ECAS messages to be broadcast and received over the existing End-of-Train radio frequency.

Figure 1 shows a block diagram of the overall EPWS/ECAS system. The three base hardware components are shown shaded. Optional connections to other locomotive equipment to achieve various alertness safety features are shown in white.

Figure 1: EPWS/ECAS System Block Diagram

EPWS Functions

The Enhanced Proximity Warning System represents an integration of two safety related systems previously developed and tested by BNSF and Pulse Electronics:

1) Rail Navigation System (RNS): Provides a means to determine locomotive location and track identification, against an onboard database. Navigation inputs are from a GPS receiver, odometer, and gyro (rotational velocity). The primary objective has been to be able to determine track identification and locomotive location very reliably without use of any ground infrastructure.

2) Proximity Warning System (PWS): Utilizes the same frequencies as the end-of-train (EOT) radios to establish train-to-train communications. This enables each locomotive to advise other trains, within a nominal range of 3-6 miles, of its GPS-based location, as well as train speed and safe braking distance.

EPWS represents a merging of RNS and PWS, to allow location and movement information to be exchanged between trains, in terms of milepost and track identification references.

The Armadillo contains the track database, which is displayed in graphical form on the Engineer Display. The database includes the following key parameters, with latitude/longitude references:

- Track layout (switch locations and track configurations)
- Milepost markers
- Curve data
- Grade profile data
- Signal locations and ID=s
- Highway crossing locations and names
- Permanent civil speed restrictions

ECAS Functions

The AEnhanced Crew Alertness System@ (ECAS) evolved as a part of BNSF=s efforts to implement crew rest and fatigue countermeasures. The ECAS concept evolved to assure crews were maintaining their alertness. ECAS enables the computer to take control of the train, bringing it to a stop, when crew fatigue is suspected or a potential rule violation is eminent. A higher level of Aalertness@ may be achieved than that which is found with conventional alerter systems.

An Armadillo-based locomotive computer system and Engineer display provides a range of safety enhancements which are independent of the EPWS functions. As an overall concept, the onboard system provides prompts that require correct crew input for continued movement authority. For example, in signal territory, this takes the form of requiring input of each signal aspect as it is being approached. The correct answer allows continued movement. Incorrect answers will result in a penalty brake application. This approach is intended to help maintain the alertness of the crew, while keeping them from becoming dependent on EPWS functions.

A description of a base set of ECAS functions is provided below. Only the entry of signal aspects and the enforcement of civil speed restrictions have been implemented to date.

1) System Initialization: A new crew would enter ID numbers (or use ID cards with an onboard swipe reader), and train length data (in 100=s of feet) on the graphical display unit. This would allow ECAS to estimate full service braking distances as a function of speed and forward grade.

2) Track Speed Monitoring: Speed increases by a defined amount over the current track speed limit (1 to 3 mph) would be alarmed both audibly (sonalert in display unit) and visually (display messages). Acknowledgment of the alarm within a set time (about 5 sec.) would provide another level of “speed tolerance” (additional 1 or 2 mph) for a set period of time (about 1 minute). Lack of acknowledgment, combined with lack of deceleration, would force a

penalty brake application. Even with acknowledgment, a penalty brake application would be made following failure to reduce speed within a defined time.

3) Deceleration in Approach to Lower Speed Limit: Approaching speed reductions may be from permanent speed restrictions or from approaching the limits of currently entered authorities. The onboard computer can generate speed-distance braking curves to estimate the ability for the train to meet the newer speed limit points. As this curve is approached, an alarm will be provided, requiring acknowledgment. If the alarm is not acknowledged within a set time, and the train does not start to slow, a penalty brake application can be made. If the alarm is acknowledged, the train can be operated Acloser to the curve@, but would still apply the penalty brake following violation of the braking curve limit.

4) Approach to a Signal: In approach to each relevant signal (relating to the direction of travel), a short audible alarm and display message can be presented, to prompt manual entry of the signal aspect. The presentation of the signal entry prompt could be provided a fixed distance from the approaching signal, by a fixed distance from the last signal, or a combination of the two. The graphic display would include the signal location by milepost reference, and a Arolling display@ of the approach distance to the target signal (in tenths of miles).

5) Signal Aspect Entry: The signal entry will generally be in terms of Ared, yellow, or green@, but would also include added aspect data, such as Aenter siding@. Following entry of the signal aspect, the display will continue to show the aspect as entered, on the track display. In the event of a signal change prior to the locomotive arriving at the signal (typically going from restrictive to clear), an Aupdate signal@ function key can be used to bring back the aspect entry menu, to allow a revised input.

6) Enforcement of Signals: Aspects as entered can be enforced, based upon the inferred limit of authority as denoted by each signal entry. In the event of lack of crew input, one aspect more restrictive than the last signal can be assumed, for penalty enforcement purposes. If there is no signal entry within the calculated safe braking distance to the signal, a penalty brake can be applied.

7) Entry of Track Warrants: In non-signal territories, at least two methods of operation could be considered for entry of limits of authority as communicated by voice radio from the dispatcher. One could be based upon entry of milepost referenced limits of authority. Another could be based upon predefining authority limits, similar to signal system blocks, for a given route. The route number would be entered upon entering the non-signal territory, and each segment could be advanced by a single key input, as successive authority limits are received.

The ECAS operation as outlined can be performed with a single engineer display unit, which also provides current location and track display in a graphical format. If required, a second display can be provided for the conductor.

The base ECAS, as described in the previous section, can be expanded incrementally to provide additional safety functions. Expanded functions which could be considered are based upon addition of hardware or interfaces onboard the locomotive, as well as ground and office infrastructure. Potential incremental addition of hardware and interfaces, and related expanded safety functions which could be added are outlined below.

1) TrainLink PWS: ECAS with an interface to TrainLink PWS can provide EPWS communications of location and train authority information between trains in the same area. Increased interlocking logic protection can be added, based upon having signal aspect information for each train added to the data being communicated.

2) Solid State Event Recorder: Serial interface to event recorders can provide brake pipe pressure information, which when combined with EOT brake pipe pressure information from TrainLink can provide train integrity and train braking performance monitoring. Actual braking performance can be compared to predicted, with alarms for poor braking trains. This information can also be used to Alearn@ the braking capabilities of the train during the trip, and adjust the speed protection braking curves accordingly.

3) Memory Card Downloader: The PCMCIA memory card reader, as optional with TrainTrax recording systems, could be shared for both ECAS and recorder functions. PCMCIA cards could be expanded in function, with cards issued to engineers (or conductors). The cards could be routinely inserted for each crew shift, and contain temporary speed restrictions, or even the entire route track database. ECAS could then write back to the cards at the end of the

trip to provide an operational summary, with start/stop times and records of signal aspect entries and any abnormal events (penalty applications, etc.).

4) Base Station PWS Repeater/Receiver Units: Addition of PWS Alistening and repeating@ units at existing voice radio base station sites can provide three added capabilities: (1) Improved RF coverage reliability for locomotive-locomotive communications; (2) Relay of PWS and EPWS broadcast data to NOC, to allow dispatcher monitoring of train movements and manual signal aspect crew entries, and (3) Provide the ability for the dispatcher to directly make penalty brake applications to trains under emergency or non-conformance conditions.

5) Office Data Radio System: The system could be expanded to work in concert with other centralized systems for advanced control of train movements. The addition of a data radio link to allow higher volume two-way data interactions between locomotives and the office control center would be required.

6) Wayside Signal to Locomotive Data Links: The need for manual entry of signal aspect information could be replaced by a variety of options for establishing a direct data link from the wayside signal system to approaching trains. This could potentially be accomplished by using either the PWS or office data radio systems.

A block diagram of a base EPWS/ECAS configuration (shaded), with options for expansion of the locomotive system is provided in figure 1.

The base ECAS configuration as described allows a means to achieve a significant safety improvement on an incremental basis, without any ground or office infrastructure additions. This system can directly address crew alertness issues, with far greater protection than conventional alerter systems. Further safety enhancements can be provided by interfacing to TrainTrax event recorders and TrainLink PWS units, as outlined. Addition of ground and office communications systems can allow further growth or interface with other mainframe train control algorithms.

Braking Calculations

A penalty brake interface is provided, which can be applied in series with the same magnet valve used for alerter applications. This provides the ability for the EPWS/ECAS system to initiate a full service brake application, in the event alarms are not acknowledged. Automated penalty brake applications may also be applied, even with engineer acknowledgment of alarms for predefined conditions. These conditions may include overspeed beyond a set tolerance level, or conflicting movements within safe braking distances to other trains.

A number of the EPWS/ ECAS functions are dependent upon knowing the braking characteristics of the train. In addition, there is a potential to further extend the system to monitor train braking performance to allow refinement of future predictions, as well as to alert the engineer of potential braking problems.

Conservative full service brake distance algorithms are used in the current EPWS/ECAS system, which are generated based upon the following inputs:

1) Current train speed
2) Train length, as entered upon system set up
3) Average forward grade over the braking distance, based upon current location on the track database

This could be supplemented by a manual train weight entry, if available. This would assist trains that due work en route to update their consist characteristics. However, in the base algorithms a conservative weight assumption is used. There may be concern of depending too much on crew entry of reported weight information, especially with intermodal trains, where weight information is often not reliable. More detailed consist information at initial terminals through a card reader or other inputs without reliance on the crew for data entry.

The braking distance assumptions used are similar to that typically used in design of block distances for signal systems. This means that they should be conservative, such that any train not able to meet them would be an exception.

The EPWS/ECAS Engineer Display shows the current braking distance prediction as a shaded extension to the train, overlaid on the train profile. This allows the engineer to see the stopping distance at a glance, related to upcoming track mileposts, signal locations, highway crossings, speed restrictions, and other trains. A marker within the shaded braking distance can be added to show the predicted distance needed to brake to the next speed restriction point as well.

Of course, there is always a trade off between how conservatively to make braking predictions and operating performance. If the onboard predictions are too conservative, they would result in an excessive warning distance, with trains needing to slow down sooner or more often than would be needed to maintain safety. This leads to a need to develop adaptive braking performance predictions, which are adjusted based upon the measured braking performance in the course of a trip.

Ideally, as service brake applications are made, the actual train performance can be checked against the predicted performance. If the train is found to brake better than in the initial conservative prediction, as would be the most common case, the safety factor could be reduced to better reflect actual capability. On the contrary, braking worse than predicted could be used to alarm the engineer of potential braking system problems, as well as to extend safety margins used in the EPWS/ECAS braking distance predictions.

Clearly, train location with detailed track database information, including grades and curves is critical to being able to make accurate measurements of train braking performance. This is already available as part of the EPWS/ECAS system. Adaptive braking prediction can be more accurate if the following information is added to that now used for the base brake distance calculation:

1) Brake pipe pressures in locomotive and end-of-train
2) Throttle/dynamic brake status
3) Traction motor current, or tractive/dynamic effort, in each locomotive

This information is readily available in the lead locomotive, based upon data coming into the EOT locomotive control unit, and adding a data interface to the event recorder. The EPWS/ECAS system already interfaces to the Pulse TrainLink EOT system, for RF communications, and EOT information is available. An additional serial interface can be provided between the EPWS system and the event recorder to pickup the traction and dynamic brake data.

Adaptive braking prediction would allow both brake system performance checking, as well as refinement of brake distance algorithms, each time a braking action is taken. This would allow significant safety improvements by helping to identify brake system problems en route, and may lead to future reductions in manual inspection requirements.

PROGRAM STATUS

The first proof-of-concept of the RNS technology occurred on the Memphis-Thayer track of the BNSF in Spring >96. A Atoolbox@ of sensors was used to record a locomotive=s movements through an active track area. Equations were developed to allow an onboard computer to track the locomotive position.

The current phase, a three locomotive pilot project on BNSF=s Topeka subdivision, started in 1996 and is nearing completion. An Engineer display was added to provide a dynamic track plan to the train crew. Grade, curve, and braking data were graphically displayed and updated in real-time. Locomotives began to broadcast their positional data to each other, allowing proximity warnings to be displayed on remote locomotives.

The next planned phase is to install updated EPWS/ECAS equipment onto ten locomotives in Southern California. This final development phase is expected to wring out any remaining production and installation issues, and to allow analysis and feedback from the user community in general. There are many options which need to be considered with respect to crew interface displays and method of inputs. This ergonomic analysis is expected to be finalized during this phase, using inputs from BNSF operating personnel.

SUMMARY

The EPWS/ECAS approach is a cost conscious here-and-now solution which can enhance the safety of railroad personnel and equipment. The major advantage of the EPWS/ECAS approach is that it achieves success without requiring any additional ground or office infrastructure. All data communications are directly between locomotives, allowing a significant advantage in the initial implementation cost, effort, and schedule, and in the long-term reliability. A broad range of effective crew alertness functions can be integrated into the existing EPWS/ECAS system.

This concept has been developed with the intent of addressing the desires and of many in the railroad industry, including the Railroads, FRA, NTSB, and several state agencies, for a technology-based method for collision avoidance. In addition, it provides a means to assess crew alertness and take control when fatigue is suspected.

EPWS and ECAS overlay existing train control systems. The railroad=s existing signal and track warrant systems remain in place. As such, they provide a redundant approach to collision avoidance.

The EPWS/ECAS technology has been proven in BNSF=s Topeka subdivision. A continued effort is planned over a wider area in Southern California.

ACKNOWLEDGMENTS

The authors would like to acknowledge Mr. George Hsu, formerly with BNSF Technical Research and Development, for his early contribution to this work. His efforts and continued support of this concept enabled its continuing development. We wish him well in his new endeavors.